INSTRUCTIONS TO YOUNG GEOLOGISTS

My geological hammer

(length of shaft one foot)

INSTRUCTIONS TO YOUNG GEOLOGISTS

by

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Illustrated by the Author

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INTRODUCTION

FIRST steps in geology are always a mixture of excitement and surprise. I dug my first fossils out of rocks on the Yorkshire coast at the age of nine, and the collecting and identifying of rocks and fossils have played important parts in most of my holidays ever since.

At times these holiday collections created problems of transport, and my father would exclude the weightier specimens from an overladen car on the return journey, but with the aid of my sister they were usually concealed in the most unlikely parts of the car, even being sat upon when necessary, and so arrived home safely.

Because geology was not included in the school curriculum during the seven years when, as a schoolboy, I lived in the Lake District, it became exclusively a holiday pursuit, and in recent years has to some extent governed the direction of holiday expeditions. It is not, I think, entirely a disadvantage to have a study such as geology excluded from the usual school lessons. It is not a " book " subject, and must in the first place grow out of a personal curiosity about the structure of landscape. As Professor Boswell said in his address to the geological section of the British Association in 1932, " Students are still attracted to geology by a pure love of the subject, just as they were in the old days of the great amateurs."

Geology is a study that leads to long visits of exploration and adventure, in which the discovery of rock outcrops and their fossils becomes an insistent challenge. Rock formations have a perverse habit of not looking like text-book diagrams, and one must acquire a working knowledge of the basic geological principles that are so essential to the fuller and increasing understanding of the subject as it is encountered in the field.

In my opinion field geology cannot be separated from field

botany and I have often found my botanical knowledge of great use, because different kinds of rocks frequently support distinctive groups of plants which may be recognised, sometimes even from the window of a bus or train.

The possession of this book and a hammer will not, by themselves, turn you into a geologist. Geology is a science, and you will find that the more you understand of it, the more enjoyment you will gain, whether by the sea coast, in mountain country and river valleys, in quarries and clay pits, and even in towns where the stones used in building can often be traced to their sources in distant parts of the country. In this connection you will remember that many people believe that the Blue Stones used in the construction of Stonehenge were brought thousands of years ago, from far away in Pembrokeshire, for use in building a temple on Salisbury Plain.

In this book I have made no attempt to isolate geology from my other interests, and have included chapters on the relationship between plants and geology, and the appearance of Man on the Earth.

From this outline I should like to think that you will start a study which will become of lifelong interest to you, and do not forget that the geology of the British Isles is probably more varied and interesting than that of any other similar area in the world.

Finally I wish to express my gratitude to Dr. W. E. Swinton for kindly reading the manuscript of this book, and for making helpful and encouraging suggestions.

I also wish to thank my parents and my sister for their help and co-operation on many expeditions, and in the more exacting task of producing a book.

Figs. 7, 13, and 23 to 27 inclusive are based by permission on maps published by the Geological and Ordnance Surveys.

CHAPTER I

HOW TO BEGIN

THIS book has been written in the hope that it will help beginners in geology to get the most out of their first explorations and expeditions. I firmly believe that the right approach to any natural science is through field work, and geology is certainly a field study.

Geology is not, as yet, widely taught in schools, and there is a general absence of guidance for the young geologist. A certain amount of basic geological theory, together with some technical terms must be understood before you can really interpret your field observations. In a book of this size it is obviously impossible to touch on all aspects of theoretical geology and I have therefore concentrated on general principles illustrating how rocks are formed in different circumstances and at different times in geological history. The more detailed geology of different parts of the country I am leaving to the excellent series of *British Regional Geology* Guides, produced by the Geological Survey.

In addition, the Survey issues one-inch-to-the-mile geological maps, and you should, as soon as possible, obtain the Guide covering your region of the country, together with the appropriate one inch map. (All the Survey's stocks of maps were destroyed during the War, but they are being steadily re-printed, and the maps of many interesting areas are now available again). These Guides certainly assume that the reader has *some* understanding of geological terms and processes and I hope that after reading this book you will be in a position to read them intelligently! You must realise that it is necessary for a geologist to know the language of his science, and experience will show that these terms are not as formidable as they may appear at first sight.

If you live near to London or can pay a visit occasionally, do have a look at the wonderful geological collections at the Natural History Museum in Cromwell Road, South Kensington, and at the nearby Geological Museum in Exhibition Road, where you will find that you can spend many happy hours studying the rocks and fossils. If, unfortunately, you live too far from London for such visits to be possible, you can buy a Guide book called *Museums and Galleries in Great Britain and Northern Ireland* (Index Publishers Ltd., 69 Victoria Street, London, S.W.1) in which you will find lists of about 120 museums up and down the country, all of which have good geological sections, together with details of days and times of opening, cost of admittance (though I am glad to say that most municipal museums are free), and full addresses should you wish to write to any of them.

Now let us consider equipment for field excursions. You will need little beyond a pair of observant eyes, a notebook, a geological hammer and stone chisel. You may find that a folding ruler is useful, and perhaps a trowel. If you are hunting for limestone you need a small bottle of dilute hydrochloric acid, but take care that you always keep it upright and well wrapped up to prevent it spilling, for even when dilute it can damage your clothing and maps, as well as your digestive system should it get mixed up with your lunch!

The notebook, preferably about 3½ inches by 5 inches with stiff covers, is essential. In this you *must* write down as many of your observations as you possibly can. Always make sure that you have put the date and your location as accurately as possible. Record that your sandpit was, say, 80 yards east of Kingsley Church, or that the particular stretch of cliff that you photographed was halfway between Burton Freshwater and Burton Bradstock. Use the inch to the mile maps of the Ordnance Survey for this, and then if you want to be particularly precise about a locality you can use the National Grid References, which are explained on each sheet. (The National Grid is also being printed on the new geological maps).

Make sketches of the rock formations and structures that you see, together with any diagrams and notes that will help you to remember what the rocks looked like, and also, the

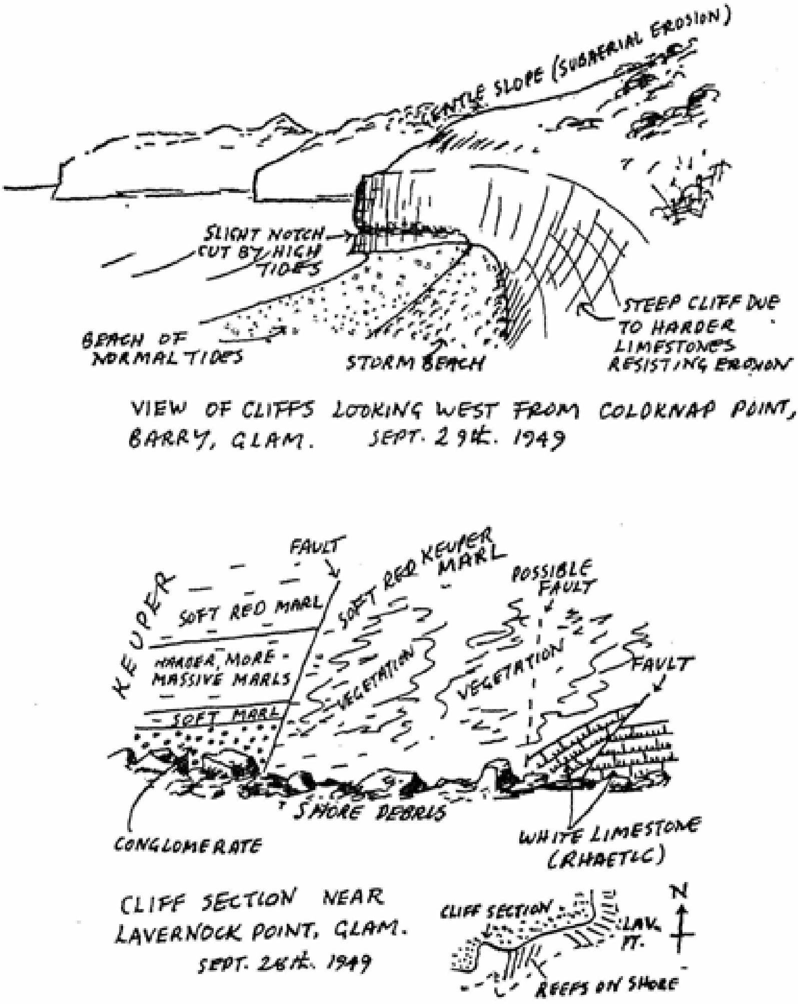


FIG. 1.
Reduced samples of field sketches, indicating the scope of the information that can be put into labelled drawings.

occasion when you visited the place. (Fig 1) Even irrelevant notes of a personal nature may help you to recall the scene, such as "Just before John dropped his hammer down the cliffs into the sea," (which, incidentally, is exactly what I did

myself near to the Fossil Forest just beyond Lulworth Cove). You should also make a collection of geographical photographs, good postcard views of cliffs, waterfalls and mountains. If you are handy with a camera you can add your own photographs of interesting places seen on your holidays. The photographs in this book were all taken by me (with the exception of Plates 1A and 1B) during expeditions and I have hundreds more that serve to recall my visits with the personal touch that the best of postcards cannot offer. The importance of making your collection of geological illustrations is that without them, even if you were able to bring home quite large rock specimens you would still be unable to show how the rock beds were originally arranged in relation to each other, or to physical features such as waterfall, bays, etc. It is absolutely no use to rely on your memory.

Your hammer must *not* be one of the ordinary household variety, but must be one specially designed for use with stone. If you visit quarrying country you should easily be able to buy a suitable tool; if not, you can obtain special geological hammers for a few shillings. One of my hammers is illustrated in the Frontispiece. This one is an old friend on which I carved down the handle the names of the more important places we had visited together, but long ago I ran out of space! Hammers have just occasionally been known to shatter when used heavily on rock, and as a precaution against this and the very much greater chance of flying rock fragments striking you in your eyes, you should wear some sort of shatter-proof goggles when hitting hard rock. Your eyes are far too precious to run the risk of damage so take a lesson from professional stone carvers and wear some sort of protection.

The actual weight of hammer and size of chisel will depend upon the kind of rock that you will be attacking. If it is very hard you must have a heavier hammer, but a lighter one is quite enough for softer material. If you can manage it I advise two hammers, and several chisels ranging from say, a quarter to three-quarters of an inch across. The chisels used by woodworkers are useless for this job.

If you are starting a collection of specimens, either of fossils or of rocks, it is essential to make a definite and accurate record of where you found the individual specimens. I cannot

over-emphasise the fact that unrecorded oddments (however exciting in shape or appearance) have little value in a real geological collection. Many of my own earlier gatherings have turned out to be quite valueless all because I did not take this care. The preliminary labelling must be done at the time, best of all while you are actually doing the collecting. Tie labels on the rock fragments or include labels as you wrap them up in newspaper. It is quite appalling how similar and confusing collections of rocks can look some months later, and if there are no labels they may well have to be thrown away. Always put as detailed records as possible in your field note-book, say, for instance that a specimen was from a loose block of stone below a certain cliff, or if it was actually in the solid rock, and if the latter, measure how far up or down it was from, say, the quarry floor or a definite and identifiable bed of rock.

The question of bringing your collection home is simply a matter of common sense. Do not put heavy rocks on top of fragile fossils or on loose sandy specimens which will disintegrate. The most fragile must be protected in cotton wool in tins. Try to avoid letting your rock samples roll around so much that they come out of their wrappings, lose their labels and bruise or damage each other. It is probably best to have a separate tough bag or sack for your geological haul, and to keep it apart from such things as your camera and sandwiches, neither of which will benefit from copious additions of loose sand grains. (I should perhaps have included sandwiches in the list of essentials, as geological expeditions have little or no connection with normal mealtimes.)

The actual manner of tackling any particular rock will vary according to its physical nature, and can only be mastered by experience.

It may well be that your rock shows horizontal layers or vertical cracks; both of these can be utilised in extracting samples by judicious use of your hammer and chisel. You will want fresh specimens, and not the weathered, brownish and partly rotten outer layers, so choose a projecting edge or corner and knock it off smartly with your hammer. The inner surface of the broken-off piece will usually show fresh unweathered rock. (Fig. 2.)

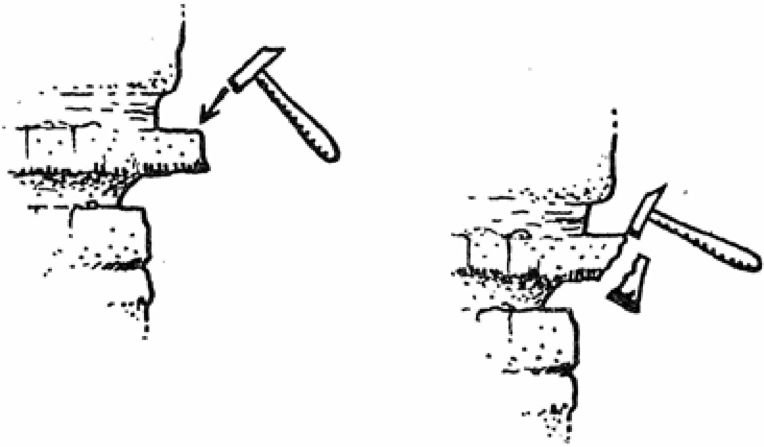


FIG. 2.
It is wise to select projecting rocks when collecting fresh rock samples.

When you are collecting fossils, you must take the very greatest care not to damage them. NEVER TOUCH ANY FOSSIL WITH YOUR HAMMER OR CHISEL. When you are trying to extract one from the surrounding rock, use your chisel cautiously, tapping it gently, and making sure that you either guide it parallel to the edge of the fossil, or stop well clear if you have to direct it towards the fossil. In shaly rocks beware of wrecking fossils that split off into thin flat layers. Make small flakes of rock jump away from the fossil at first, and then when it is well exposed, you can make the fossil jump out cleanly. Do not be dismayed by your efforts even though you may smash some before you learn how not to use your chisel. Only experience can teach you how much to attempt in one effort. I have seen partially exposed fossils on which somebody has spent some hours of patient work, before realising that they had taken on too big a job.

Very often it is far preferable not to try to extract a certain fossil from the rock, but to bring it home still partially buried in the rock matrix. You may prefer to extract it at home, using a fine chisel and light hammer, or merely to tidy it up but still leaving it attached, especially if it is reluctant to come out or would be damaged in the process. (Plate 1B.)

It is a good idea to wash, or maybe scrub specimens when you get them home, but again, never scrub any specimen with anything harder than itself. A stiff brush may be suitable for a piece of granite, but it would ruin the fragile remains of a shell embedded in clay. Clay samples are always best left unwashed.

CHAPTER II

ORIGIN AND STRUCTURE OF THE EARTH

BEFORE you can understand the origins of the raw materials of field geology or the working of the more important geological processes it is necessary to know something about the internal structure of the Earth and its probable origin.

The origin of the Earth has been a matter of philosophic speculation since men first saw the sun set, but modern scientific investigation suggests that the Earth came into being about 3,000,000,000 years ago.

Early theories suggested that the Earth was thrown off a swiftly revolving sun, like a spark from a Catherine wheel. More recent theories suggest that another star, passing near the sun, pulled out a filament of solar substance which condensed into the planets as we know them. These are interesting speculations, but for our present purpose have no special significance.

You will already know that the Earth is nearly spherical, and that rotating on a polar axis the speed of rotation is zero at the Poles, and about 1,000 miles an hour at the Equator. The increased speed of rotation at the Equator has created an outward pull and an accumulation if substance at the zone of maximum rotation, increasing the equatorial diameter by about 26 miles.

In considering the structure of the Earth, the major problem is that nobody can penetrate far enough inside to investigate. The deepest coalmine in this country (which is uncomfortably warm) is only 3,550 feet deep, whereas a radius of the earth is more than 20,000,000 feet.

Nevertheless, by studying the movement of earthquake waves and by calculations based on estimates of the Earth's

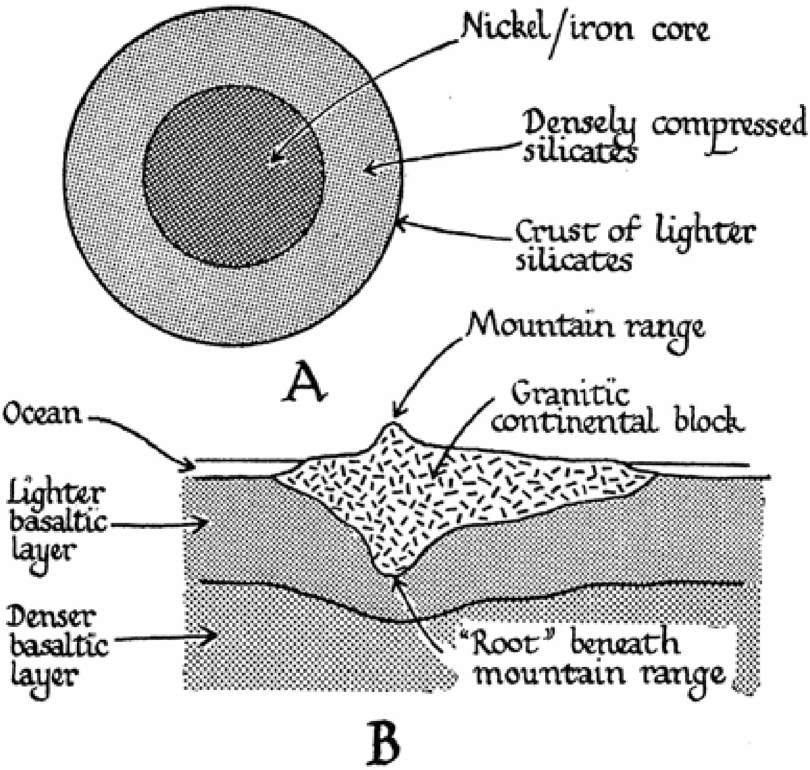


Fig. 3.
Diagrammatic sections through (A) the whole Earth, and (B) a part of the silicate crust.

gravity and density in different places, geologists have produced a picture of the probable conditions in the interior of the Earth.

If we went down a shaft, say, 2 miles deep, we should find that the temperature of the rock walls would increase by 1°F. for every 65 feet down. If at the foot of our shaft there were any water, it would be boiling. If, by any means the shaft could penetrate to a depth of 20 miles, the rock walls would be molten.

In actual fact, of course, molten rock does come to the surface in volcanoes, and boiling water spouts out of geysers, as well as sometimes being found in deep mines. It is well

known that when certain Alpine tunnels were being bored, boiling water spurted out from the rocks.

The molten rock is probably more correctly visualised as being more solid than liquid because it is under enormous pressure, even though at so high a temperature. This pressure is due to the weight of the outermost layer of rocks, some 20 miles thick, which has cooled to form a more or less rigid crust. If a weakness should occur in this crust because of movements underneath, it may crack locally and the lower rocks may liquefy (in which state it is called MAGMA) and escape through fissures as LAVA which will solidify as it cools.

The general sequence of rock types is made clearer in Fig. 3. The centre is composed largely of iron and nickel surrounded by concentric layers of various silicates of different densities. The lightest silicates (the granitic layers) float on the denser basaltic layers, but the granitic rocks do not in fact form a continuous shell but are distributed mainly in the large continental masses, with gaps (mainly covered by oceans) where the basaltic layer comes to the Earth's surface. There is, perhaps, some parallel to the condition of a blast furnace where the silicate slag in iron smelting is floating on a core of molten metal.

Granitic and basaltic rocks produce two types of magma, that of the latter usually being hotter and flowing further than the former, which is cooler and stiffer, so we find that basaltic lava covers the greater areas. Magma reaching the Earth's surface forms EXTRUSIVE igneous rocks, but when it merely lodges in cavities within the surface layers, it forms INTRUSIVE rocks.

You will be familiar with the normal form of a volcano, a conical hill, perhaps steepest at the top where there is a crater from which are ejected hot ashes and gases, together with very hot rock fragments and sudden outflows of lava. A volcano of this type has a central pipe or VENT up which the hot material travels, though sometimes it may branch to produce subsidiary cones on the side of the main one.

The cone is formed from successive layers of lava and ash; which produce a very rich soil, and we find that wherever it is safe enough the slopes of volcanoes are intensively cultivated. Should a volcano of this type become inactive for a long

period, the pipe may become blocked by cooling magma. Later, when it once more becomes active, enormously increased pressure beneath this solid plug will blow it out as the volcano erupts. If the eruption is destructive enough the whole top of the mountain may be blown off, and much of the crater walls may collapse and be swallowed up into the cavity where the magma used to be, leaving an immense crater, perhaps many miles across, known as a CALDERA. Old calderas are often full of water now, and are called crater lakes.

There are other types of volcano which eject little or no ash, and these throw out mainly lava, and differ very much in shape from the better known ash-cones. If the lava be acidic (i.e. granitic) it will only flow for a short distance before solidifying, and steep sided domes will be produced, like the extinct volcanoes in the Auvergne mountains of France. Basaltic lava will flow very much further, and will produce domes of gentle slope covering extremely large areas, such as those in the Hawaii islands.

When basaltic lava rushes out in great quantity at once, it may spread over the surrounding countryside in a horizontal sheet, perhaps about 25 feet thick, and covering many hundreds of square miles.

Later lava flows would then spread out on top of this, the total thickness being considerable. Such old basalt flows cover the Deccan in India, and another series used to extend from northern Ireland and western Scotland across to Iceland and Greenland. The basalt columns of the Giant's Causeway and of Staffa are part of this mass of basalt, and I have seen the component flows extending horizontally for miles along the coast of Skye.

The last great outburst of basalt was in 1783 when the volcano Skaptar Jokul in Iceland sent out in succession two streams of lava which, taking the paths of least resistance, flowed down two river valleys for distances of 45 and 50 miles, causing the water to run in other directions and much of it boiled away. One stream of lava flowed over what was earlier a waterfall, and filled up the gorge with basalt to a depth of 600 feet.

In Wales, the Lake District and Scotland, volcanoes used, during several geological Periods, to be important parts of the

scenery of what is now Britain, leaving as evidence vast thicknesses of rock formed from volcanic ash, and innumerable perplexing exposures of intrusive igneous rocks.

In further study you will need to know the different types of form and structure shown by igneous rocks.

Granite usually occurs in enormous intrusive masses forced in between the layers of overlying sedimentary rocks, and presumably fed originally from some central point deep underground.

We can see only the eroded tops of these masses, called LACCOLITHS (Fig. 4) an example being the granite of the

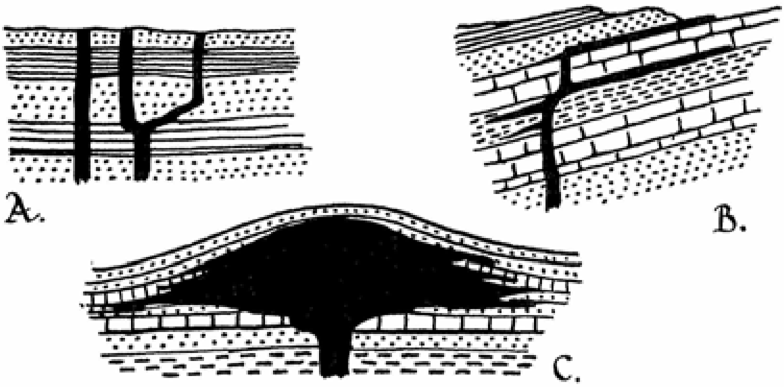


FIG. 4.

Vertical sections through (A) a group of dykes, (B) sills, and (C) a laccolith.

The laccolith is on a much reduced scale compared with the dykes and sills. The igneous rocks are drawn in black.

Cairngorms intruded during the late Silurian (see Chapter VI).

If the magma solidifies inside vertical cracks, it will form vertical sheets or walls called DYKES, and where these are very numerous (as are those radiating from the much denuded cores of the old volcanoes in Mull and Ardnamurchan), they are called DYKE SWARMS.

One dyke from Mull actually extends to within a few miles of Whitby on the Yorkshire coast. If the dykes are inclined outwards from a common centre as a series of cones, they are called CONE SHEETS or RING DYKES.

If, on the other hand, the magma cools in a horizontal position wedged in between layers of sedimentary rocks (which are described in Chapter VII), it produces a SILL, a good example being the Whin Sill in Yorkshire. Extrusive lava forms LAVA FLOWS, such as those already described in Iceland, often with gas bubbles in their upper parts, and when they were erupted under the sea their surfaces cooled so rapidly that overlapping folds or pouches were produced. These lavas are called PILLOW LAVAS, and examples may be found on Cader Idris.

CHAPTER III

MINERALS AND IGNEOUS ROCKS

YOU may think that there is little to connect the calm British countryside as it is now with vast volcanic eruptions, but the connection lies in the igneous rocks, samples of which may have found their way into your collection from time to time. These rocks are very hard and are definitely crystalline when broken.

When molten rock escapes as magma from the Earth's interior it immediately begins to cool and crystalise into solid rock. The process, which is really a form of freezing, is complicated by the fact that magma contains a mixture of melted chemical compounds, each compound having different physical properties. Thus, as the magma cools we find it has formed a mixture of variously shaped, sized and coloured crystals all packed together, very closely.

Practically all igneous rocks are crystalline, and this can be seen easily in such a rock as granite, where you may find crystals as much as four or five inches long (Fig. 5). In the main, the size of the crystals is governed by the rate at which the magma cools. It is only when cooling is very slow that the crystals have sufficient time to grow to so large a size as this. When cooling is more rapid, the crystals may be so small as to be visible only under a microscope, and when extremely rapid the cooling may be so sudden that no crystals are formed at all, and the rock may be quite glassy.

In describing and identifying igneous rocks it is necessary to have some knowledge of their chemical composition as indicated by the proportion in which the different minerals are present, but because the chemical make-up is often complicated, this account will be limited to the briefest descriptions of the most important minerals that you are likely to come across.

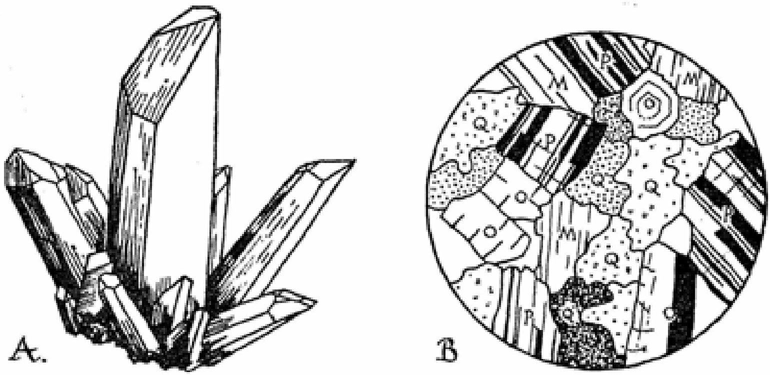


Fig. 5.
(A) Well developed quartz crystal, half natural size.
(B) Transverse section through a piece of granite as seen by polarised light. X 10.
Some of the constituent crystals are lettered:
M—Muscovite. O—Orthoclase. P—Plagioclase. Q—Quartz.

The following are the principal rock-forming minerals.

Silicon is probably the most important single chemical element present in rocks, occurring combined with oxygen as silicon dioxide, referred to chemically as Silica, and when crystalline as Quartz. Silica may further be combined with metals in varying amounts to produce the substances known as silicates. Rocks containing much silica are said to be acidic, whilst those with only a little are said to be basic. Quartz is often abundant in acid rocks, where it is found as small ill-formed crystals lying between the other crystals, but in spite of its abundance it is not very conspicuous. The crystals are glassy and colourless, and break with an uneven surface. Quartz is in fact the main constituent of, for example, ordinary window glass. Sometimes quartz crystals grow perfectly and to a large size in cavities of a cooling rock, when they are known as Rock Crystal. Quartz is quite hard, in fact too hard to be scratched with a penknife. As a result, and because it is so stable chemically, it is the most resistant mineral to weathering of those commonly met with.

Prolonged exposure to water and to the atmosphere may destroy all the other minerals, converting them to other softer products which can easily be washed away, but the quartz remains unaffected. Vast quantities of quartz grains liberated

in the first place from igneous rocks form the sands of the desert areas, of our sea coasts and of the massive sandstone deposits such as those of the Millstone Grit in the Pennines.

FELDSPAR is the general name given to groups of closely related sodium, potassium or calcium aluminium silicates, which are present in almost every igneous rock and which may often be the principal constituent.

There are three types, namely, ORTHOCLASE (containing potassium), and two kinds of PLAGIOCLASE, one called ALBITE (containing sodium) and one called ANORTHITE (containing calcium). These crystals are white or pinkish, and usually with well developed crystal faces and shining split surfaces. You have probably noticed that if you look at an orchard of fruit trees from a moving bus or train the trees appear to be arranged in lines with spaces between, but that if you move on a little the same trees seem to arrange themselves into new lines with new spaces between. The molecules in a crystal are also arranged in a definite pattern, and we find a number of spaces between them as between our fruit trees. It may be that the three dimensional symmetry of our crystal is like a whole series of orchards standing one on the top of another, in which case the spaces become parallel planes. These planes in a crystal are called cleavage planes, and it is along them that the crystal splits. Feldspar is soft enough to be scratched with a knife, and is fairly easily converted by weathering to softer substances still.

MICA is distinguished by its extremely thin plate-like crystals resulting from the exceedingly well developed cleavage planes. Sheets of mica will bend without breaking and are slightly elastic. There are two types, one white or colourless called MUSCOVITE (containing potassium and aluminium), and the other dark brown or black called BIOTITE (which contains in addition, magnesium and iron, to which it owes its dark colour). The sheets of mica used for insulating electrical apparatus are taken from extremely large crystals found in rocks known as PEGMATITE.

CHLORITE is related to the micas, but is characteristically green and occurs in large quantity as small flakes and scales in rocks such as the slates of the Lake District.

PYROXENE covers a group of complex silicates with variable

chemical composition. This is because the various molecules are interchangeable within a crystal. Examples of pyroxenes are Diopside and Augite. These minerals are usually green to black in colour, again because they contain iron and magnesium.

Amphiboles are related to the pyroxenes, and are sometimes difficult to separate from them. They differ chemically in containing combined water in the crystals. The most important amphibole is Hornblende, whilst a related mineral of great commercial value is Asbestos. This name actually covers any amphibole with long flexible fibrous crystals which can be woven into fabrics which are very heat resistant.

Olivine is a yellow-green glassy mineral when fresh, once more consisting of a series of related magnesium and iron silicates. It is very easily converted into Serpentine, a hydrated magnesium silicate, with the liberation of the iron as the oxide called magnetite. Serpentine is a massive greenish substance which is particularly abundant in Britain at the Lizard peninsula in Cornwall, where it is carved into ornaments for sale to visitors. A related mineral is Talc, an extremely soft silvery or greenish flaky substance which constitutes French Chalk when it is ground up.

The more magnesian olivine cannot exist in the presence of free silica, when it would be converted into pyroxene.

Garnets are iron and calcium or aluminium silicates which crystalise with more or less perfect form, their brownish or red glassy crystals having twelve or twenty-four faces most commonly, in spite of being embedded amongst other crystals. Small garnets frequently occur in some igneous lavas, a well known locality being Stye Head Pass in Cumberland, where I have found several specimens.

Iron Oxides are the principal source of iron, which, unlike the precious metals such as platinum and gold, rusts quickly to an oxide of some sort. The principal iron oxides are Haematite which has a rounded lumpy surface, Magnetite, a magnetic shiny black mineral, and Limonite which is a non-crystalline rusty brown rather earthy looking deposit. Limonite is the principal material responsible for the cementing together of the hard " iron-pan " which is found a foot or so below the ground surface in sandy districts.

Calcium Carbonate is not found as an original constituent of igneous rocks, because the heat would disintegrate the molecules. It is of course the principal mineral in the numerous sedimentary limestones including chalk. Crystalline calcium carbonate (Calcite) may look rather like quartz, and veins of this material may resemble quartz veins in the field. But calcite may easily be distinguished because it can be scratched with a knife, shows cleavage planes and bubbles on the addition of dilute hydrochloric acid.

Igneous rocks owe their hardness to the fact that the constituent crystals interlock very closely, and because of this very tight arrangement, in which the shape of each grain is affected by its neighbours, it is only very rarely that any particular mineral can develop into a large and perfectly shaped crystal. On those few occasions when this does happen, and provided that the mineral is hard enough and is sufficiently attractive, we may treasure such crystals as gemstones.

Some gemstones are merely coloured forms of quite ordinary minerals, but this matter of colour is rather confusing, because the colour of any particular gemstone may vary through quite a range. Thus crystals of Sphene may be yellow or green, and yet have essentially the same chemical composition. The colour variations seem to be due to very minute amounts of coloured chemical impurities.

Diamond is undoubtedly the most famous gem of all. It has many curious properties. It is the hardest known substance, has the highest refractive index of any gem and is composed solely of the element Carbon. It differs from Graphite (used for pencil "leads") in the pattern of its three-dimensionally arranged carbon atoms, and it can in fact be turned into graphite by heating. If it be heated in air, it can be burned away to gaseous carbon dioxide.

Corundum is the next hardest mineral, and its coloured pure varieties are well known as gems, the red being the Ruby, and the blue, yellow, green and purple known as the Sapphire. The impure corundum known as Emery and the artificial corundum called Carborundum are used as abrasives.

Beryl again shows a considerable colour range, the most valuable being the velvety green Emerald, probably the most

expensive of gems at the present day. The bluish green form is called AQUAMARINE.

Other well known gems include SPINEL, PERIDOT, ZIRCON, TOURMALINE, GARNET and TOPAZ. QUARTZ has also been used as a gem, together with its purple form called AMETHYST, as also has the purple form of FLUORSPAR, known in Derbyshire as Blue John. In addition there are a number of opaque minerals which may show bright colours and which are cut and polished for decorative purposes such as OPAL, TURQUOISE, JADE and LAPIS-LAZULI.

It is unfortunate that it is rather difficult for a beginner to identify igneous rocks, but you will probably find that it is wiser to collect specimens from an area where individual outcrops are few, and can be named by reference to geological maps and detailed descriptions. Whenever you have the chance you should study named specimens which are in the museum.

You are certain to come up against the names of many igneous rocks as you read about physical geography, so a brief summary follows to tell you a little about the main rock types. You will find that this is based upon the presence or absence of the minerals we have already discussed, especially quartz, and on the size of the crystals in the rock.

The most important igneous rocks are those derived from a magma rich in silica, the quantity present being sufficient to convert all the basic metallic oxides to feldspars, micas, etc., but still leaving sufficient excess silica to crystallise as quartz. Rocks of this general composition are referred to as being ACIDIC. If the feldspar is mostly orthoclase, the rock is called GRANITE, if mostly plagioclase GRANODIORITE. It is normally pinkish in colour, and fairly coarse grained, the coarse grain indicating slow cooling at some depth underground, since these are instrusive rocks.

Finer grained extrusive lavas in this group are RHYOLITE and DACITE. When a large mass of granitic magma slowly cools underground, contraction fissures develop in the outer surfaces. Here crystallisation proceeds in very favourable conditions, and we get the largest crystals ever formed, in the rock called PEGMATITE, filling the cracks. Fairly large crystals of feldspar may occur in a granite proper, such as the famous

pink Shap Granite from Westmorland. Rocks of this type are said to be PORPHYRITIC.

The next most important group of rocks includes those derived from magmas containing insufficient silica to convert all the metallic oxides to feldspars, micas, etc. Some of these may exist instead as feldspathoids (whitish minerals related to feldspars), and olivine, together with plagioclase feldspar and pyroxenes. There are of course no quartz crystals. These rocks, generally called GABBRO when they are coarse grained, DOLERITE when medium grained and BASALT when fine grained, are all darkly coloured because of the predominance of iron and magnesium-containing minerals, which are mainly green, brown or black in colour. These are the BASIC igneous rocks.

Intermediate between these two main groups are the various SYENITES and DIORITES (of coarser grain) and the lava-forming TRACHYTES and ANDESITES (of finer grain). These rarely contain quartz and are sometimes composed of considerable amounts of the more basic minerals. They do not, however, occur very frequently.

As you learn more about these difficult rocks, you will find that their nomenclature becomes very complicated, and we will leave rock names such as HAUYNOPHYRE and PHLOGOPITE-LEUCITOPHYRE to the expert petrologist.

CHAPTER IV

EROSION

THE various processes that go under the general name of EROSION are probably the most important of all geological processes, for without them the Earth would be completely uninhabitable; but exactly what it would look like one can barely imagine, because almost all the land-forms most familiar to us such as mountains, valleys cut by rivers, sea cliffs, even the soil itself, are all the direct results of erosion. To a geologist the erosion of past ages is made abundantly clear from the study of the numerous end products such as sandstones and clays.

Considering the ways in which our igneous rocks are broken down by the normal agencies of weathering, we might ask why such rocks should change at all; why should not a mass of granite stay unaltered for ever?

We must remember that the various minerals which make up such a rock were formed at very high temperatures, many hundreds of degrees hotter than those now met with at the Earth's surface. Although they were probably stable and in equilibrium with each other at these high temperatures, they certainly are not stable in our present climatic conditions. The result is that various chemical reactions occur (especially in the presence of water), which tend to change most of the rock-forming minerals into new substances.

A few of the rock-forming minerals are so resistant as to be unaffected during chemical weathering, in this group are quartz and the white mica, muscovite. Others however, and in particular the feldspars, readily break down to other materials. Soda and potash are freed from the feldspar, and, in the form of soluble carbonates, can dissolve silica and decompose other silicate minerals. The aluminium from the

silicates ends up as minute scaly crystals of certain clay minerals of complex chemical composition. These crystals are colloidal, that is, they are so small as to remain indefinitely in suspension in water, but are too large to be in true solution. When ferromagnesian minerals such as augite and hornblende break down, the iron oxide limonite is ultimately formed, and is responsible for the brown rusty appearance of weathered rock. The clay minerals are the source of the clay deposits laid down by rivers in their lower reaches, all the clay having been derived directly from the chemical breakdown of igneous rocks.

Sometimes the clay particles formed from feldspar undergo a further reaction leading to the hydrated aluminium silicate called KAOLIN, which is extensively mined in Cornwall and used for pottery. The Cornish kaolin or CHINA CLAY may also have been derived from feldspar in the nearby granite, by the effects of hot chemically active gases during the final cooling of the granitic magma.

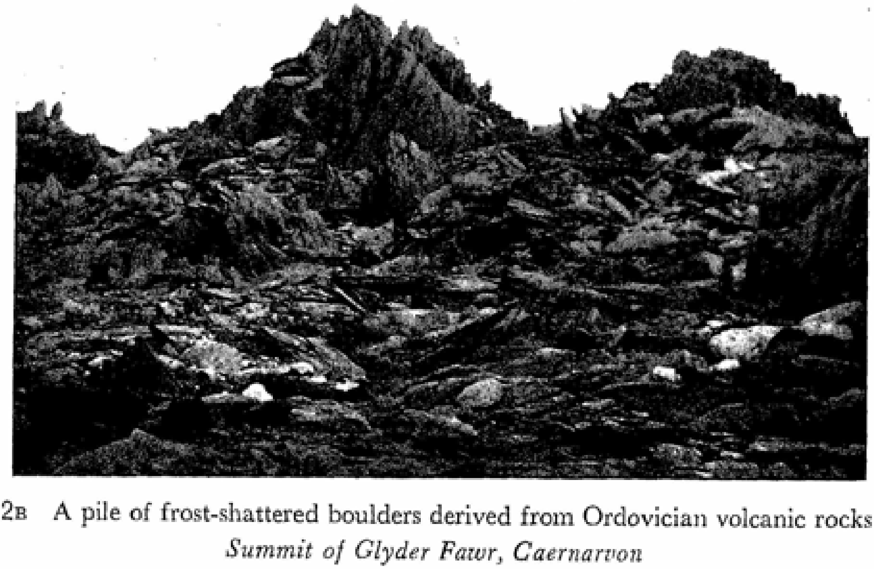
Another form of chemical erosion is seen when calcareous rocks are weathered. In Britain the best area for studying this is the Pennine limestone country, but similar features appear in many other parts of the world, notably in the Pyrenees and the Karst country of Jugoslavia and Czechoslovakia, the latter having been studied in great detail. The purer limestones consist almost entirely of calcium carbonate, and this is dissolved by slightly acidic rain water containing carbonic acid in solution, derived from the carbon dioxide of the atmosphere. Solution starts along cracks and planes of weakness, also along the horizontal planes between and within rock beds.

On inclined surfaces these channels may join together in much the same way as do the tributaries of a river. I have examined several fine examples of this on Carboniferous Limestone at Hutton Roof in Westmorland. The cracks become widened and deepened into clefts perhaps a few inches wide, but many feet deep and are called GRYKES, the thin dividing walls of rock being called CLINTS. These terms are sometimes used in a more general sense for an area of limestone containing numerous grykes or clints respectively. They thus come to mean much the same as limestone PAVEMENTS, flat weathered

1A Digging out my first fossils at Ravenscar, Yorkshire

1B Extracting an ammonite from a chalk block

2A Residual perched boulder due to weathering of granite
Province of Biera Alta, Portugal



2B A pile of frost-shattered boulders derived from Ordovician volcanic rocks
Summit of Glyder Fawr, Caernarvon

expanses of rock where all the overlying strata have been removed down to a particular bed, which is then exposed over a considerable area, as in Plate 4A.

Underground, this solution of limestone reaches its maximum development, and the cavities become enlarged into caverns of spectacular size. The vertical shafts of these underground cave systems are called POT-HOLES, and can be exceedingly dangerous for an inexperienced explorer who ventures inside because heavy rain outside, even though some distance away, may cause the water-ways within the caves to rise suddenly and cut off retreat. By colouring the water in upland streams, the course of such streams can be traced by looking for the emergence of the coloured water from some underground cavern. Thus, in the Yorkshire Pennines, the stream from Malham Tarn disappears almost immediately into the ground to reappear some three miles away and 300 feet lower down as the River Aire in Malham Cove. The adventures of the River Aire are not over as it has yet to pass through the city of Leeds!

Water seldom runs for long on the surface of limestone, as it usually meets some fissure down which it vanishes. When there is a cover of soil to the rock, conical depressions called " sink holes " are formed at these points. I recently encountered sink holes in great quantity on a most curious mountain near Pralognan in the Savoy Alps. This mountain was composed of practically nothing but gypsum, and its slopes were covered with extremely steep sided sink holes about fifteen to twenty feet deep, and separated only by a few inches of gypsum at the top. Gypsum is a hydrated calcium sulphate, white and very soft, which weathers extremely easily. It is, incidentally, of great economic importance, being the source, amongst other things, of blackboard chalk.

Chemical weathering, then, leads to the destruction of most rock forming minerals, which generally end up as clay minerals or in solution in water. Only the tough grains of quartz and flakes of muscovite (with a small number of much less common minerals) remain unaltered. These become freed from their decomposing surroundings and can be washed away by rain, blown away by the wind or merely fall down to a lower level.

Chemical weathering is really a series of chemical reactions, and these, as you know, proceed faster at higher temperatures. Hence the fastest chemical breakdown of rocks happens in the Tropics, as for instance, in Malaya where solid granite can be decomposed down to a depth of thirty feet. There is however little or none at high altitudes or in the Polar regions where it is so much colder, and in these places physical weathering takes over.

All rocks have some cracks or lines of weakness in them. These may take the form of parallel jointing following the contraction of the rock from its molten state, or may follow earth movements which have broken the rocks in places. Rain-water or melted water from snow will enter these cracks and cavities and in the winter (or at night during the summer) will freeze to ice. Ice has a greater volume than water and the rocks will consequently be forced apart, being prized open as the ice expands. When the ice melts the damage is already done (exactly the same as when your water pipe freezes and bursts), and moving water can help to shift the broken pieces. The extremely rugged peaks of the High Alps are formed in this way.

I had a grim experience of this kind of weathering when, in 1936 I visited the charming little village of Boedals on the shores of Lake Loen in Norway. On the opposite side of the lake towered the almost vertical Ravnesfjell, a great mountain rising over 6,000 feet above the lake. The following day, as we were on our homeward journey, news came through that a gigantic slice of this mountain had crashed into the lake, and in the matter of minutes had sent up a " tidal wave " that had wiped out the village of Boedals, every house, tree and every living creature. This disaster had been caused in part by water from the glaciers forcing its way into crevices, freezing, and later thawing, thus loosening the rock. I visited this same spot last summer. The gash in the mountainside and the mound of rock debris rising out of the lake are all that remain to tell one of the catastrophe, for no new village has grown up on that desolate and denuded shore.

A particular kind of weathering found in some massive igneous rocks is that known as Onion Scale Weathering, in which successive layers of rock are split off from a boulder

which becomes more and more spherical as time progresses. In our climate this peeling takes place in the main by chemical decomposition of the outer layers, but in warmer regions a similar result follows the alternate heating by day and cooling by night which, owing to the consequent expansions and contractions, split off curved scales, leaving a rounded core of rock behind. I have seen numerous examples of onion scale weathering in Portugal, some on a spectacular scale. Thus the uppermost boulder in Plate 2A is some 20 feet high (a man beside it gives scale). These boulders are residual blocks of granite in the mountainous province of Biera Alta in Northern Portugal.

Once our igneous rock has started to break up, the process can continue with great speed, especially if the loosened and detached fragments are removed, and it is here that streams and rivers play their parts. Moving water carries the fragments away downhill, rolling the largest, whilst the intermediate ones may be partly carried with the current and partly rolled. The smallest will be carried much further, the distance being roughly inversely proportional to their weight.

These stones are actually responsible for a considerable amount of erosion, though the stranded rocks in a dry mountain stream bed may give little clue to this. During heavy rain the streams suddenly become raging torrents and the repeated batterings of hurtling boulders are able to carve deep gorges in the surrounding rocks, particularly hard rocks being worn smooth and whitened by the innumerable impacts.

The steep sided wadis of North Africa are similarly carved out from horizontal layers of rock by the enormous erosive powers of boulders caught up in the floods following occasional immense downpours.

The physical effects of erosion are innumerable, but they all follow certain general trends operating on different scales. The main trends are downhill movement of particles under the effect of gravity, and the lateral movement resulting from displacing forces, such as wind and running water. The observant eye will detect erosional effects wherever looked for in the country, and I think that it is particularly instructive to seek for explanations of large scale phenomena in terms of smaller forms. Thus, the main erosional features of the lower

courses of a river can be seen in miniature in the form of a temporary stream draining, for example, a pool on a sandy beach. If you can imagine yourself to be very small indeed, perhaps only a centimetre high, and to be standing beside such a stream, very little more imagination is needed to think of this valley in the sand in terms of a life-sized valley, and to pick out the corresponding features, the erosion cliffs and terraces, the slipping of pieces of earth on steep slopes, the meanders of the river, the deposition of sandbanks and the stranding of earlier drainage channels. It is only necessary to remember that it is happening very much faster in our sandy stream and perhaps more easily, because the sand grains do not stick together in the same way as the particles in ordinary soil, and certainly not as in hard rock.

The study of the form of the eroding countryside is becoming of increasing importance, and is honoured with the name GEOMORPHOLOGY.

The modern attitude is to describe what amounts to theoretical stages in the evolution and development of a perfect, idealised river for instance, and then fit in our real river to the stages of evolution which fit it best. We must remember that the geomorphologist's hills, rivers, valleys and coastlines are theoretical ideals, and it is only very rarely that we find actual examples that seem to be so perfect. This is not because the geomorphologists are wrong, but because there are so many factors at work in the field, other than those directly responsible for the construction of a particular land form.

Let us consider the form of a river valley. Generally speaking the headstreams that rise in the higher hills have boulder beds, and run very fast in steep-sided V-shaped hollows. Their actual flow will be very closely linked with rainfall, and in a rainless summer may dry up altogether. As the stream is joined by others, the tributary streams will be separated by sharp edged spurs, which will interlock when one looks up or down the main valley. These higher parts of the river are eroding actively, and at each bend in the stream the water current will cut away fastest on the outer and downstream side of the bend, where a steep sided cliff develops. On the inner side erosion will be negligible, and limited accumulation of shingle may occur (see Fig. 6A).

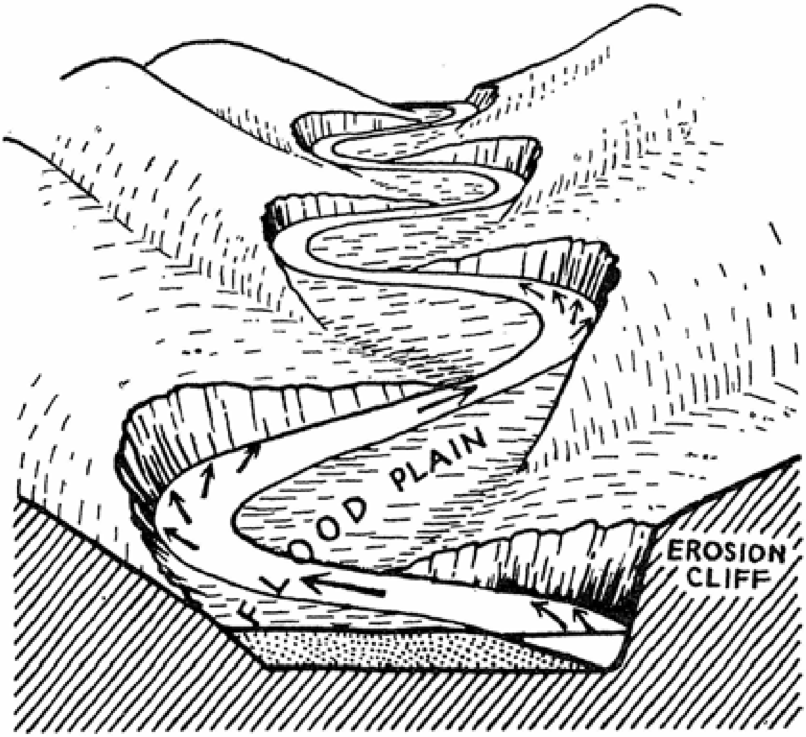
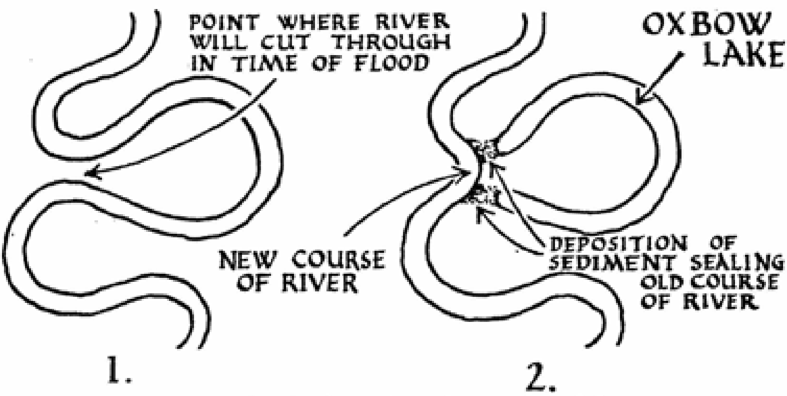


Fig. 6.

(A) Diagram to show how river meanders move down stream by lateral and forward erosion along valley sides, with formation of flat flood plain. Small arrows show direction and position of maximum water erosion.



(B) Two stages in the formation of an ox-bow lake.

In the course of time the river acquires a wide, flat FLOOD PLAIN covered only in times of flood. This results from the removal of projecting spurs by the river bends or MEANDERS, as they move steadily downstream. When all the projecting spurs are removed and the meanders are moving freely within the flood plain, the valley is said to be "mature." The meanders may become so sinuous as to lead to the river taking short cuts in times of flood, and cutting off meanders which later develop into OX BOW LAKES (see Fig. 6B), finally perhaps to fill completely with sediment and vegetation.

Of necessity this erosion is followed by DEPOSITION. If the river runs at length into calm waters of a lake, or into the sea, it will drop what remains of its load, the coarser particles first, and the finer ones later. Mature rivers will have only the very finest clay particles still to be dropped, but those that are faster flowing will be carrying sand and silt as well. In deposition the coarser sediments will build up into a roughly fan-shaped delta, traversed by numerous branches of the river called 'distributories.' The successive additions to the delta take place almost entirely at the forward edge, where the slope is the steepest possible for particles of the size being deposited. The resulting deltaic beds are characteristically curved in section, showing what is called CURRENT BEDDING, and as the slope is related to the direction of water flow, we can use the slope of fossil deltaic beds to tell us which way the water flowed during those earlier times.

Gravity alone causes the deposition of mud in freshwater lakes, but in coastal waters where mud-bearing river matter meets the salt sea water, the clay particles are precipitated by a process in which the electrical charges on the clay particles are neutralised by the ions of salts in solution. Mud banks are formed in quantity along the sides of river estuaries but on shores where the river runs directly into the sea the mud is washed along the shore to accumulate in more sheltered places.

You know that a river will adjust its valley to the nature of the surrounding rocks, if they are soft and erode fast it will be wide, but if they are very hard and resistant it will be narrow. Similarly a hard bed of rock may cause a waterfall, as the softer rocks around and beneath are gradually washed

away. It is also worth remembering that waterfalls, for instance, are not purely fortuitous in their appearance, but must of necessity indicate the presence of differences in rock hardness. Lakes also indicate variations in local geology, but almost always owe their basins to ice erosion during the Pleistocene Ice Age, as will be described later. A few, as for example the Cheshire meres, follow the subsidence of the ground when soluble substances are removed in bulk from underneath (in the case of Cheshire it is the rock salt). Others, such as the East African rift valley lakes, and the Caspian Sea, follow definite land subsidences over a large area.

The horizontal strata of sedimentary rocks often weather into alternating cliffs, where the rocks are harder, and more gentle slopes where they are softer, as is well seen in an immense scale in the Grand Canyon of the River Colorado in Arizona, and nearer home, in the limestone scars of the Pennines. Subsequent earth movements have often tilted the once horizontal beds, and differential weathering will then pick out the inclined strata, as shown in Fig. 7 for part of

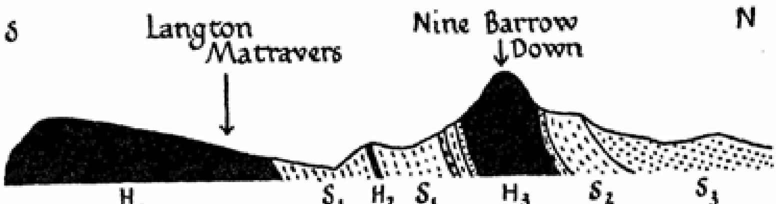


FIG. 7.

H_1. Hard Jurassic limestones. H_3. Hard chalk.
S_1. Soft Cretaceous clay. S_2. Soft Eocene clay.
H_2. Hard Cretaceous grit. S_3. Soft Eocene sand.
Length of section: 4 miles.
Vertical scale: 4 x horizontal.

Transverse section through the Isle of Purbeck to show how the relief has been governed by the hardness of the rocks. The Jurassic beds contain a considerable quantity of soft shales, but the numerous very hard limestone bands serve to reinforce them, and the total effect is to give quite a resistant formation.

Purbeck, Dorset. The prominent hills forming the North and South Downs are due to the greater resistance of the chalk

outcrops, the chalk being gently tilted in most places at about 2 to 5 degrees.

Chalk may not appear to be particularly hard, and one may be surprised to find it forming such prominent features as the Needles in the Isle of Wight, but in that particular area it is exceptionally hard, so hard in fact as to be used locally for the walls of houses and churches.

On a much smaller scale, differential weathering can pick out beds of differing hardness within a single deposit, as in the Blue Lias cliffs at Lyme Regis (cementstone and softer clay or shale), and the cliffs of Burton Bradstock sand where the hard layers are merely a sand similar to the rest, but strengthened with iron oxide. These last named localities are along the coast, and it is undoubtedly true that the best places in Britain for examining geological sections and structures are coastal ones. In this we are most fortunate in being entirely surrounded by the sea. and since the geology of this country is unusually varied the British geologist has easy access to an unrivalled series of rock exposures.

The sea coast is essentially a zone of land where there is an endless struggle going on between erosion and deposition, one being dominant in some stretches, and the other in other places. The actual form of any particular stretch of coast depends upon the past history of the region with its established drainage pattern and distribution of hills, also whether the land is rising relative to the sea or sinking (a matter to be pursued in detail later), and, of course, on the solid geological structure.

A very irregular coastline is generally the result of the drowning by the sea of sinking coastal valleys (the Thames estuary is a good example), rather than by any great wave erosion, which tends to produce a straight coastline. Active erosion with the immediate removal of fallen material leads to vertical cliffs, excepting of course where soft clays are being attacked, and an inclined slope with mud flows develops.

If however, some of the fallen material is not washed away, it will be thrown up at the foot of the cliffs as a beach which may in some cases grow to such a size as to protect the cliff from further erosion, an example being the cement stones at Kimmeridge in Dorset.

Another way in which the wave erosion loses in efficiency is when the flat wave-cut platform below the cliff becomes so wide as to cause the waves to break at some distance in front of the cliff base. The wave-cut platform is revealed in many places, as for instance where the chalk cliffs, at very low spring tides are seen to be almost horizontal.

The rate of recession of sea cliffs will vary according to the nature of the rock and the degree of exposure. Thus basaltic cliffs in the west of Scotland show by their weathering and plant cover (especially slow growing lichens) that although there is little or no debris below, it is only occasionally that cliff falls occur. At the other extreme, the Boulder Clay cliffs of Withernsea on the Yorkshire coast are moving inland at about five or six feet a year.

When deposition or accretion becomes dominant, we find characteristic accumulations of sand or mud, in fact the variously sized fragments derived from the erosion of sea cliffs or of land within the catchment areas of rivers in the vicinity. The ordinary beaches show parallel ridges or crests, which are formed during extra high spring tides, or during storms. These

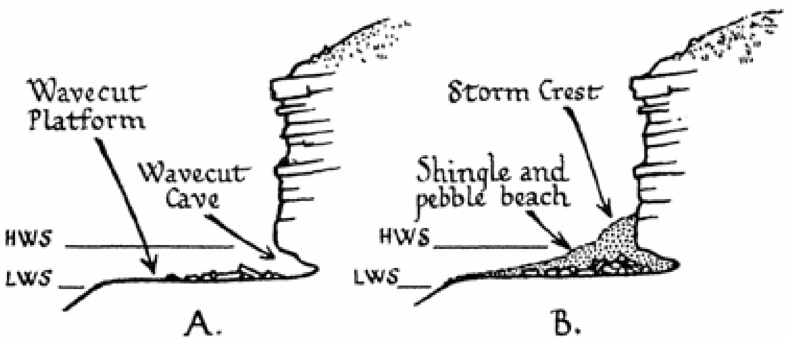


Fig. 8.

H.W.S.: High Water Spring Tides.
L.W.S.: Low Water Spring Tides.

(A) Section of a typical sea-cliff, where current and wave action removes fallen debris, erosion exceeding deposition.

(B) Section in locality where deposition of beach shingle exceeds erosion. Such a beach may well cover an earlier wave cut platform. The cliff base is now protected from wave erosion as long as the beach persists.

ridges change from time to time, there being the smallest number a few hours after a very high tide, and the maximum number of ridges at the neap tides following such a tide. Each ridge is caused by the shingle being thrown up by wind-blown waves, for without wind there would be no waves (Fig. 8).

In some places, particularly well defined tidal currents close to the shore, aided by powerful storm waves breaking from some fairly constant direction, cause a most pronounced movement of beach material along the coast. The best development of such a beach in Britain is the eleven miles SPIT called Orford Ness in Suffolk, stretching from Aldburgh to Shingle Street. Here the southerly drift of shingle (which actually starts in an easterly direction at Sheringham in Norfolk), reaches its maximum. A single spit of this type is composite in form, and is made up of a whole series of partly overlapping ridges (called FULLS) between which are elongated depressions (called SWALES). Another example is Chesil Bank, stretching from West Bay in Dorset, south-east towards Portland Bill, a distance of eighteen miles. This encloses a stretch of water called the Fleet. There has clearly been a movement of shingle from somewhere, but unfortunately we do not know from which direction, as the present beach seems to be in a state of equilibrium. Nevertheless there is a striking change in pebble size, the smallest being found at the West Bay end, and the largest at the Portland end. This, however does not appear to be true for the pebbles below water level, which seem to be graded in the opposite direction.

Shingle spits are often characterised by recurved tips which turn in landwards, these hooks being formed during severe whole series of such hooks are very beautifully developed at Blakeney Point in Norfolk, to the west of Sheringham, where winter storms often in association with new shingle ridges. A the coastal drift is in the opposite direction to that described earlier. The actual tips of these large spits are usually in a very unstable condition, and some storms will, instead of forming new hooks, completely demolish earlier ones. I myself drew a map of the Blakeney shingle spits when I was studying there, but a few years later I found that my map was useless as the coast had altered completely after winter storms.

A simplified diagram of the Erosion Cycle is shown in Fig. 9.

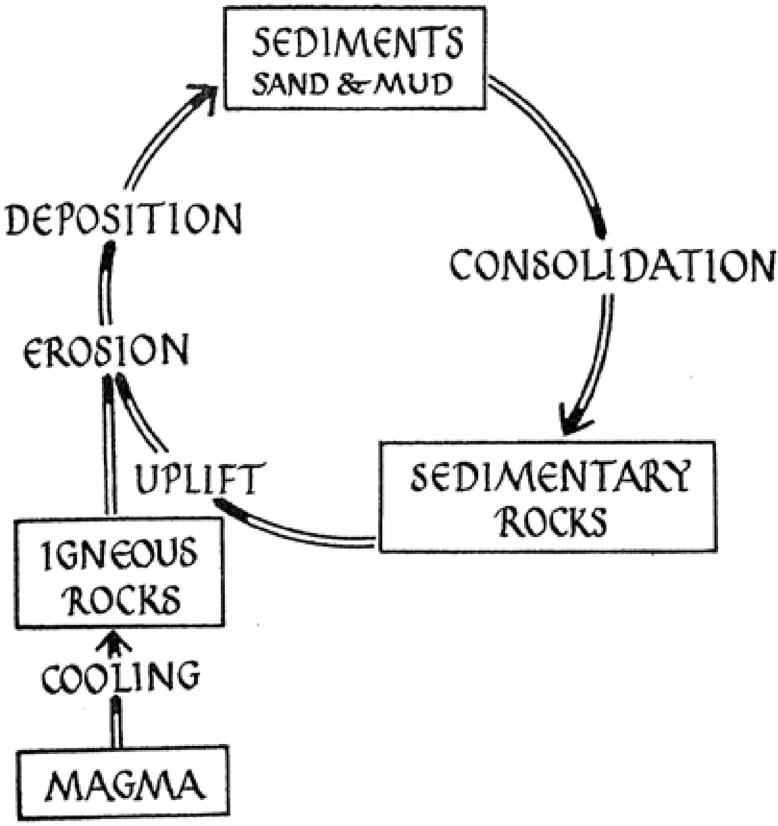


FIG. 9.

Simplified diagram to summarise the EROSION CYCLE.

CHAPTER V

SEDIMENTATION AND CONSOLIDATION

ONE of the fundamental assumptions of geology is that the deposits of earlier times were formed by processes which are continuing at the present time. It is by studying the different types of deposits now being formed that we can explain how the varied rocks of the Carboniferous Period, for instance, were laid down as sediments perhaps 250,000,000 years ago. We must examine deposition wherever it is occurring: as scree in the high mountains, the accumulation of wind-blown volcanic dust near to active volcanoes, the wind-blown sand in the dry desert areas, in the sand and silt beds of river deltas and in the offshore mudbanks in quiet waters. All of these could, given the right conditions, become converted in the course of time into hard rocks.

We have already seen how the coarsest fragments move the shortest distance from the original weathering rocks, but that the finest particles may travel many hundreds of miles. This excludes, of course, the special case of the large boulders called ERRATICS which are carried by moving ice; this is considered in the chapter on glaciation.

The finest sediments derived directly from the continents occur in the sea, beyond the edge of the continental shelf down to a depth of about 15,000 feet, and are predominantly very fine bluish muds. The very finest of all are those accumulating in the ocean depths far beyond the reach of any material washed down from the land. The main type is called the GLOBIGERINA OOZE (Fig. 10), a creamy deposit formed mainly from the minute calcareous shells of the unicellular animals called FORAMINIFERA which float on the surface waters of the ocean. The most abundant shells are named *Globigerina.*

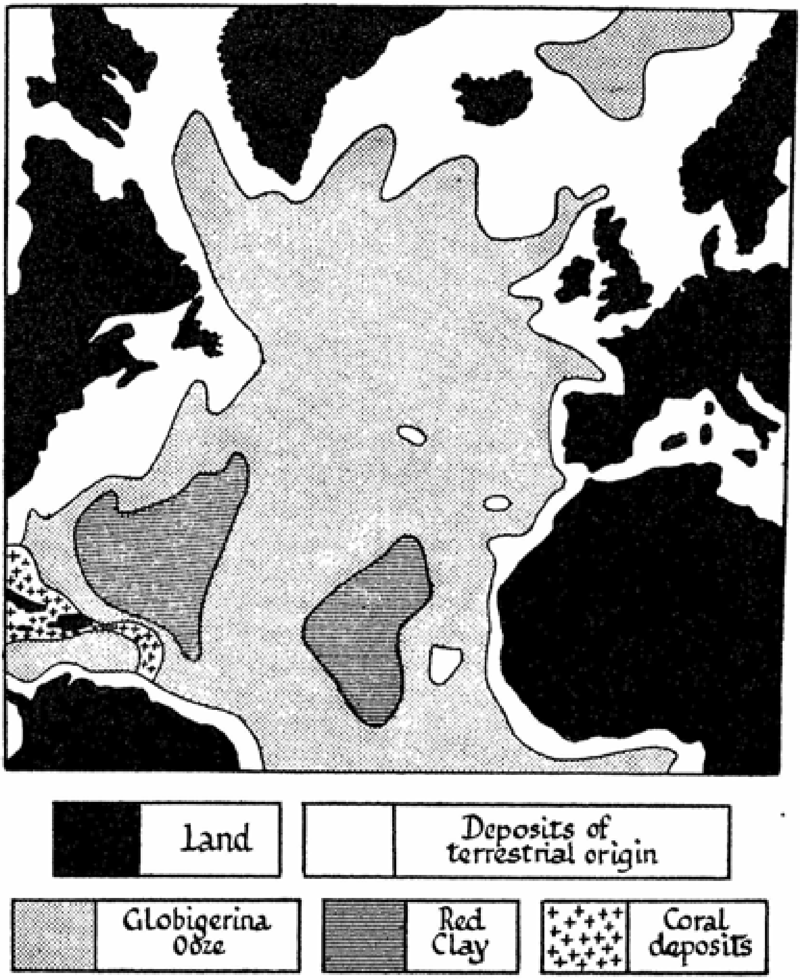


FIG. 10.

Map of the North Atlantic to show the approximate areas covered by the principal sea-bottom deposits.

The next important type is the RED CLAY and related deposits which form in the very deepest water at an exceedingly slow rate, taking something like 10,000 years for one inch to accumulate. This red clay is mainly composed of volcanic dust carried from the continents by strong winds, but other materials are also found in it. In addition, a silica ooze com-

posed of the shells of the unicellular plants called DIATOMS is characteristic of the cold south polar seas.

There remains one important group of sediments that has so far not been considered. You will remember that practically all the eroded rock material was converted into particles of other minerals which are sooner or later deposited by gravity, but what of those parts that were dissolved away? Chemical analysis shows that most rivers are rich in dissolved salts, and of course the sea most certainly so, about 3.4 per cent of its weight being a mixture of various salts. Some of these salts are precipitated under special conditions, especially when evaporation is extreme in hot climates. The first two soluble salts to be deposited from sea water are calcium carbonate and calcium sulphate, and these will be precipitated long before such very soluble chemicals as common salt or sodium chloride. It is significant that the two principal sedimentary rock types assumed to have been formed by chemical precipitation are limestone (mostly calcium carbonate) and gypsum (calcium sulphate). In certain circumstances inland waters rich in soluble substances will also form chemical precipitates, as for example the familiar stalactites and stalagmites, and the calcareous deposits called TUFA, which are all derived from the very soluble magnesium and calcium bicarbonates by loss of carbon dioxide. Bacteria in some acid waters help in the deposition of hydrated iron oxide. You are sure to know of some sluggish stream with a gelatinous rusty deposit on its bottom, accumulating round colonies of different species of iron bacteria.

Some famous belts of fossil plants have been preserved because the vegetation was immersed in water which proceeded to deposit a protective layer of some chemical without giving them a chance to rot away. Thus the fossil cycads of the Lulworth and Portland district (for long thought in Dorset to be fossil birds' nests!) were covered by a Jurassic calcareous tufa, and the curious preserved plants of the Devonian period at Rhynie in Aberdeenshire were immersed in siliceous water of igneous origin, and are now found in blocks of silica called CHERT, with internal structure perfectly preserved.

You will realise that the main difference between the present day sediments and the sediments of past ages as we see

them today, lies in that the former are generally loose or UNCONSOLIDATED, whilst the latter are usually hard, compacted or CONSOLIDATED. The process of consolidation of a sediment is called LITHIFICATION, that is, the making of it into a rock. Do not forget, though, that geologically speaking even a soft clay is still a rock.

Lithification is mainly the result of great pressure due to the weight of superimposed sediments. Such pressure may well squeeze out some of the water, for instance, a clay, producing a harder MUDSTONE, or a SHALE splitting into thin sheets. Further pressure on such rocks (generally because of horizontal earth movements), causes the clay particles to recrystallise, with the production of new scaly minerals such as chlorite. This happens because the clay crystals are virtually touching and there is no more water to be squeezed out. Recrystallised rocks of this kind are known as SLATE and they split easily along cleavage planes arranged at right angles to the direction of pressure. Many of the Welsh and Lake District sediments, formed originally from immense falls of volcanic ash, have been converted into the slates now used for roofing houses. The original rock structures have been altered so much though, that these rocks are really metamorphic.

If the intense pressure causes closely packed crystals to melt slightly at the points of contact, and then to fuse together, we can get a consolidated rock where the change is one stage less drastic than the total recrystallisation in slates and other metamorphic rocks.

A very frequent way in which unconsolidated rocks are lithified is seen in the conversion of loose sand into sandstone. Water can percolate easily through a sand, where pores between grains occupy a large part of the volume. Various substances may be deposited to form a CEMENT between the grains, which will then be held together. The most common cement is silica, which may form a continuous mass between all the grains in which case we have a QUARTZITE. Calcite may similarly act as a cement to produce CALCAREOUS GRITS. The hydrated iron oxide, limonite, is often deposited round each grain as a thin skin, which is the reason why sea-sand usually has a yellow hue. If this limonite skin is dissolved off artificially, a colourless sand is left consisting only of quartz.

CHAPTER VI

GEOLOGICAL PERIODS

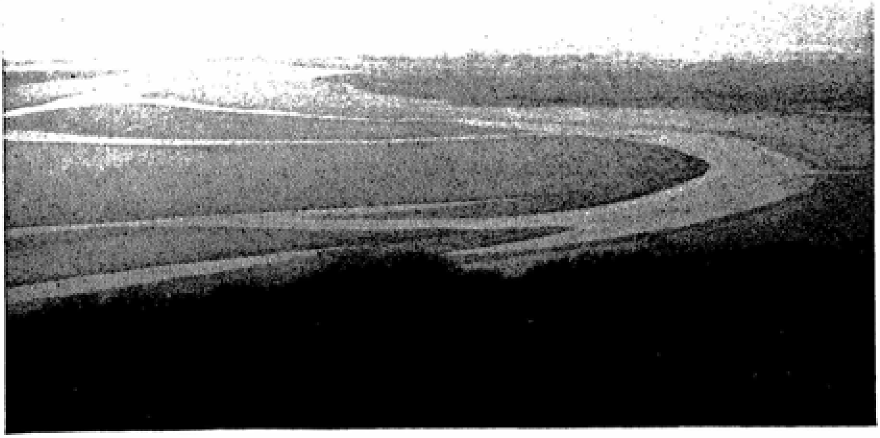
AT the risk of being repetitive I want to stress again that it is one of the main principles of geology that all rock deposits were originally formed by processes that are still going on today, although perhaps on a reduced scale and perhaps in some far distant part of the world. It is no longer necessary for us to call in the help of any supernatural explanation such as Noah's Flood or the miraculous transformation of animals into stones, as in the case of the Whitby ammonites which were thought to have been serpents that their patron saint, Saint Hilda, kindly changed into stones, an incident which is commemorated to this day in the town's coat-of-arms. We have now traced the progress of the different stages of the erosion cycle, and have seen how present-day processes could produce the wide variety of igneous and sedimentary rocks that occur in the surface of the earth.

The essence of the erosion cycle is that uplifted land is worn down, and is transported by the rivers to the sea, where it accumulates as a marine deposit. The deposition of sediments has not progressed steadily, at the same rate and in the same manner all through the ages. On the contrary there have been countless changes and breaks in the sequence of geological events at any given spot on the earth's surface.

These changes and breaks have mostly been caused by changes in the distributions of land and sea, and by uplift and subsidence of land areas.

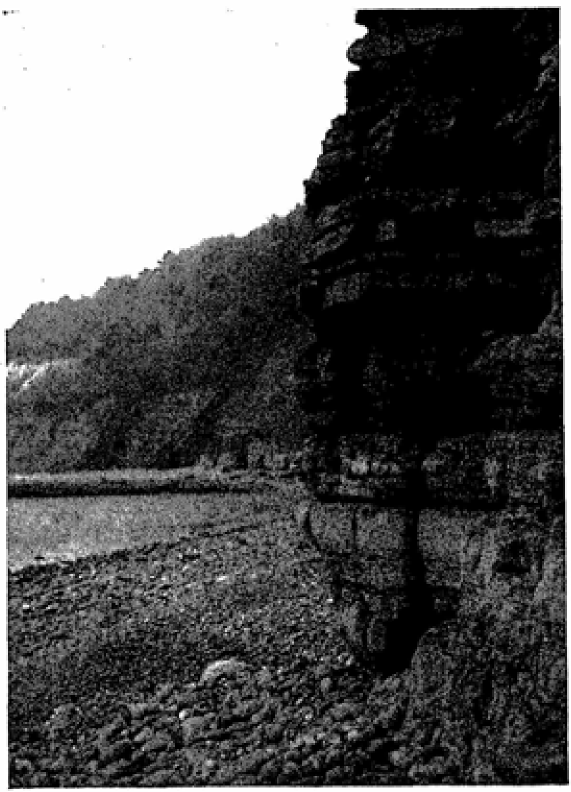
Well-marked changes of this type, which are responsible for the kind of rock being laid down, are used by the geologist to divide the immensely long ages during which sedimentary rocks have been formed.

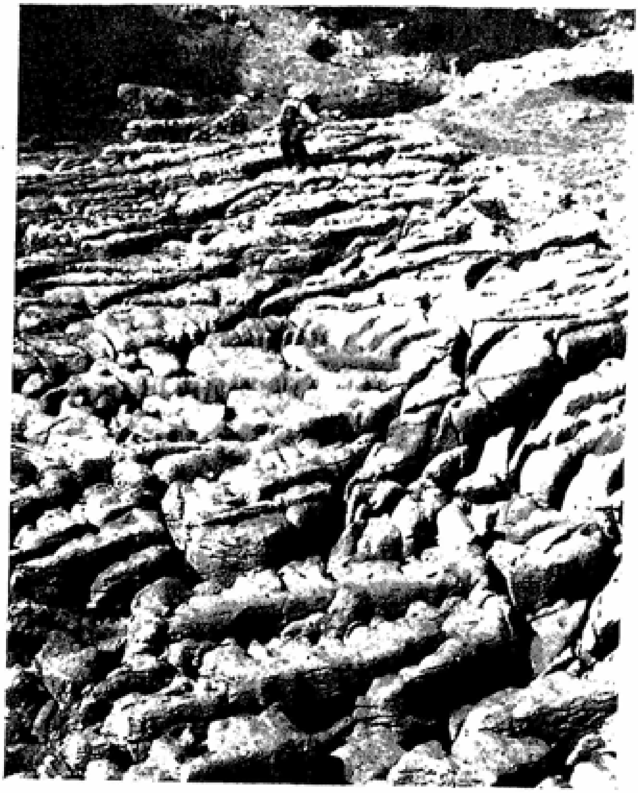
The major intervals of time resulting from this division are



3A Deposition of water-borne silt and sand. *Estuary of River Gilpin, Westmorland*

3B Stratified sedimentary rocks: Rhaetic limestone below, Blue Lias above. *Pinhay Bay, Devon*





4A Clints and grykes on pavement of Carboniferous Limestone *Hutton Roof, Westmorland*

4B Doggers (very hard concretions) in Jurassic Corallian beds. *Osmington, Dorset*

ERA	Period or System	Duration in years	Number of years since start of Period
Cainozoic	Quaternary: Recent, Pleistocene	1,000 000	1,000,000
	Tertiary: Pliocene	14,000,000	15,000,000
	Tertiary: Miocene	17,000,000	32,000,000
	Tertiary: Oligocene	15,000,000	47,000,000
	Tertiary: Eocene	21,000,000	68,000,000
Mesozoic	Cretaceous	72,000,000	140,000,000
	Jurassic	27,000,000	167,000,000
	Triassic	29,000,000	196,000,000
Palaeozoic	Permian	24,000,000	220,000,000
	Carboniferous	55,000,000	275,000,000
	Devonian	43,000,000	318,000,000
	Silurian	32000,000	350,000,000
	Ordovician	80,000,000	430,000,000
	Cambrian	80,000,000	510,000,000
Pre-Cambrian	Pre-Cambrian	*not known*	*not known*

FIG. 11.

called PERIODS. Each Period was dominated by a combination of climate and geography more or less peculiar to itself, which means that each Period is notable for certain characteristic rock types. Similarly, a characteristic flora and fauna lived during each Period, depending on geographical and climatic conditions at the time, and also on the stage of evolution which plant and animal life had reached. The group of rocks formed during a particular Period is called a SYSTEM, thus the rocks of the Silurian System were formed during the Silurian Period.

The various rock Systems, together with the appropriate lengths of the corresponding time Periods, are shown in Fig. 11.

You should remember that the number of years given are only estimates based on quite a variety of methods of measurement, some of which are fairly accurate, but some not at all accurate.

Although they may not be correct in detail, they are approximately right, and amongst other things will show you the immensity of geological time, when you realise that the last million years of the Pleistocene Period can only be represented on my diagram by the thickness of the line. You must always think in terms of millions of years, and you will see that small errors and differences do not matter greatly.

Have another look at the table shown in Fig. 11. Perhaps you will find a difficulty in remembering the order of the different Periods. Here is a mnemonic which may help you, a string of words whose initials read in the same order as the initials of the Periods.

China Owls Seldom Deceive Clay Pigeons, They
Just Chase Each Other, Making Preposterous Puns.

These initials will give you Cambrian, Ordovician, Silurian, etc. So if you learn the nonsensical lines about the China Owls it will not be so easy to get your geological Periods in the wrong order!

Now the rocks of each System may be varied in detail, so we further sub-divide each System into several SERIES. Series of rocks are again composite, and the still smaller groups of

rock beds which make them up are called Formations. You will find that each rock series and formation is named after a place, perhaps a village or a mountain. Examples are the Wenlock Limestone, named after Much Wenlock in Shropshire, and the Skiddaw Slates, named after the mountain Skiddaw in Cumberland. These are the places where the rocks in question were first described in detail, and are referred to as their Type Localities.

We have already mentioned that strata can also be grouped more accurately into Zones by means of fossils limited to successive zones. This has led to another, parallel, classification of strata, but over a much wider area than would be allowed by the local formations described above. Zones, determined by fossils are grouped into Stages, again named after Type Localities, mostly on the Continent. In the Cretaceous Period the five Ammonite Zones of the Gault and Upper Greensand together form the Albian stage, whilst the Chalk is composed of the Cenomanian, Tyronian and Senonian Stages.

This business of dividing up rock beds by fossils and rock types is much more developed for the more recent rocks, especially the Jurassic and Cretaceous, than for the earlier Systems such as the Ordovician and the Silurian.

CHAPTER VII

SEDIMENTARY ROCKS

WE saw in Chapter V how sedimentary rocks came to be formed, and we have already encountered many important types. There are others, however, in addition to these, and this is an appropriate point for a summary of the different types of sedimentary rock, with a few examples and comments on their conditions of formation.

1. FRAGMENTAL deposits are the sediments composed of fragments of pre-existing rocks, the most usual classification is according to the particle size.

The coarsest deposits are those consisting of actual pebbles and pieces of rock. If these are rounded and are cemented together into a coherent mass, the rock is called CONGLOMERATE. A conglomerate would probably have been formed from the accumulation of river-worn stones or from a sea-

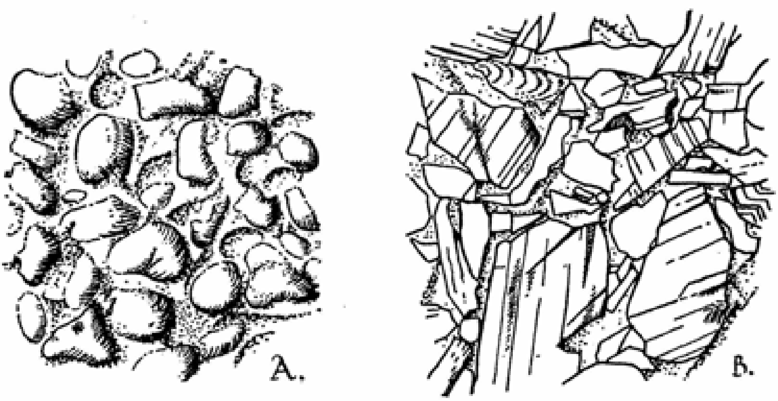


FIG. 12.

Surfaces to show the difference in fragment shapes between (A) a conglomerate, and (B) a breccia.

beach, the latter being the origin of the important Basal Conglomerates which underlie many formations.

A good example of a conglomerate is the Hertfordshire puddingstone of Eocene age, which is cemented gravel deposit. Uncemented gravels are very numerous, but are rarely more than about one million years old. If the fragments are angular and unworn, the rock is a Breccia (Fig. 12). Similar in appearance is the Fault Breccia, which occurs where rock has broken up along the plane of movement between two blocks. These fragments may be cemented together with calcite, as along the Craven Fault above Malham Cove in Yorkshire.

The next group of deposits includes those that are composed mainly of sand grains, usually quartz, but possibly with a little feldspar and muscovite, and perhaps a few grains of garnet, zircon, iron oxide, etc. If as is usually the case quartz is dominant, then the rock is known as a Sandstone, but if feldspar is abundant then it is called Arkose. A famous arkose is the Pre-Cambrian Torridon Sandstone of Wester Ross, in the Scottish Highlands, which is rather coarse and reddish brown because of the feldspar. Coarse sandstones are sometimes referred to as Grits, such as the Carboniferous Millstone Grit.

When much of the mineral glauconite is present, the rock becomes green, and if grains of glauconite are mixed with quartz we have a Greensand. The Upper Greensand of S.E. England shows this very clearly, but the Lower Greensand usually weathers brown, and may be green only when fresh.

I have already referred to the various substances which can act as cements, changing a loose sand into a consolidated rock. Quartz produces a Quartzite, although a similar type of quartz rock follows intense heating of pure sand or sandstone, when more or less complete fusion and recrystallisation occurs. A typically resistant quartzite is the Stiperstones quartzite west of Church Stretton in Shropshire. When calcium carbonate is the cement, we have a Calcareous Grit (called a grit whatever the particle size, because it weathers to give a gritty feeling surface), an important example being the Calciferous sandstone of the Lower Carboniferous deposits of Scotland.

Iron oxides form some of the cement in such rocks as the Devonian sandstones and those of the Permian and Trias, where the predominant colour is red or brown. Many of these consist of much-rounded sand grains which have been blown to and fro for considerable periods in desert areas.

A Micaceous Sandstone is one containing numerous shining flakes of muscovite. When they lie parallel to the bedding, as they usually do, the rock splits easily along these planes. Such a rock makes up much of the Yoredale Sandstone of the Pennines.

The finest grained deposits are composed of a mixture of very small particles of crushed quartz, feldspar, etc., together with the minutest flaky crystals of the clay minerals which are derived from the chemical weathering of igneous rocks. They are commonly and collectively called Clay.

A common deposit of this kind in past times has been a grey clay corresponding to the Blue Muds of the present day, an example being the Gault of S.E. England. Sometimes similar clays may be coloured by particular minerals, as for instance the green clay at Bembridge in the Isle of Wight, which is coloured by glauconite. This latter clay is actually calcareous and is thus strictly a Marl. Clay that has lost some of its water by compaction becomes harder and is called Mudstone, and if calcareous, Cementstone. This harder calcareous matter is often collected together into intermittent beds of rounded or flattened lumps called Nodules, each of which frequently contains in its middle a fossil or small stone. Such a stone or fossil may well have rolled around on a muddy shore or in shallow water, and gradually have picked up a ball of stiff mud around itself, which in due course becomes a nodule.

Other nodules and beds seem however to have been formed in the rock after deposition by the calcareous matter sorting itself into distinct layers. I have found many flattened nodules in the Lias at Robin Hood's Bay in Yorkshire, where they are specially abundant, and some have contained very good fossils, particularly ammonites.

The black oily shales from the Kimmeridge Clay of Dorset are an example of a clay formed in stagnant water on the sea bed where there was no oxygen and where no animals

other than bacteria could live. Shells of the animals floating on the surface did fall into the depths however, where the softer parts were slowly turned to oily substances. Subsequent pressure has made these rocks into SHALE, which splits easily into thin layers. The Kimmeridge " coal " is an oil shale caused by masses of organic matter having decayed under anaerobic conditions. On various occasions attempts have been made to commercialise this oil, but never very successfully. Nevertheless I know fishermen at Kimmeridge who always keep in a stock of this " coal " for their own use. It is a dull black rock which will ignite if a match is applied and burn with a heavy smoke and foul smell.

A more successful commercial oil is petroleum which is also the product of organic decomposition.

A rock of similar origin to the Kimmeridge shales, though much older and harder, is the black fossiliferous shale of the Lower Silurian in the Lake District.

BOULDER CLAY is the mixed deposit of crushed rock fragments which may be of any size from the very finest up to boulders many feet across, derived from the ground moraine of the great Pleistocene Ice sheets (see Chap. XV). The actual composition will vary according to the type of rock over which the ice sheet has moved. Thus, in parts of East Anglia the so-called Chalky Boulder Clay is highly calcareous, and contains crushed pebbles of chalk picked up from the chalk exposed on the floor of the North Sea. Other boulder clays may be sandy and lime-free. DERIVED fossils may often be found in boulder clay, that is fossils derived from earlier deposits, such as Jurassic clays or from the Chalk.

BRICKEARTH is a very fine-grained deposit, similar to the wind-blown loess of China. It is found in the S.E. of England and seems to be composed of the very finest particles from glacial deposits, but the presence of pebble beds suggests that it may not all have been wind blown, but that some was probably carried by moving water.

2. CHEMICAL deposits are those formed by the accumulation or precipitation of chemicals in quantity, often because of the evaporation of water. The most important are the calcareous LIMESTONES, which are essentially calcium carbonate,

together with a certain amount of clayey impurities. A convenient field test for these rocks is to apply dilute hydrochloric acid, which will fizz with bubbles of carbon dioxide.

CHALK is a very pure limestone with only two to three per cent of impurities, consisting in the main of minute particles of calcite of organic origin. At the other extreme some of the black limestones of the Carboniferous contain much greater amounts, perhaps as much as twenty-five per cent of impurities. It might be mentioned here that the Carboniferous Limestone is a most variable deposit, and in places may be quite crystalline; a feature of the very oldest limestones where all the calcium carbonate has often recrystallised, often when heated under pressure. When this has happened completely, we have the metamorphic rock called MARBLE. Most limestones contain numerous shell fragments, with a smaller number of complete shells, and we can usually discover the conditions in which they were formed by looking at these fossils. Thus the Wenlock Limestone of Shropshire contains innumerable beautifully preserved corals and trilobites, indicating that it originated as a most extensive coral reef, in shallow water.

OOLITIC limestones are those where the calcite has been precipitated chemically as minute spheres, looking a little like some insect eggs, about one millimetre across. Examples are to be found in certain beds of the Carboniferous Limestone and in the Jurassic building stones near Bath and at Portland Bill. The oolitic structure is best seen on a weathered surface.

Calcium carbonate is precipitated from lime-rich water when it evaporates, and we find various types of CALCAREOUS TUFA, sometimes nodular, sometimes concentrically layered and crystalline, as for instance, in the stream flowing down the chasm of Gordale Scar in West Yorkshire. The elongated masses hanging down from the roofs of caves are called STALACTITES, and the much flatter masses on the cave floors are called STALAGMITES. You can see many particularly beautiful and strangely shaped stalactites in the caves of Ingleton in Yorkshire and Castleton in Derbyshire which are open to the public.

DOLOMITE is a type of limestone composed of the mineral dolomite, a double carbonate of calcium and magnesium. The rock making up the Dolomite Alps was deposited as such, but

some other dolomites, as for example some in the Carboniferous Limestone of South Wales have been transformed from ordinary limestone after deposition by water containing magnesian salts. The Permian Magnesian Limestone is a variable mixture of calcium carbonate and dolomite, and outcrops from Yorkshire to the Durham Coast. It is well seen at Knaresborough in the West Riding, where one can visit what is locally known as the "Dropping Well," where the water dripping from the cliff above encrusts gloves, old boots and so on with a magnesian tufa, giving them the appearance of having been made of some rugged stone.

The sedimentary IRONSTONES are also formed by chemical precipitation and are frequently oolitic. Examples are the Cleveland and Northamptonshire Ironstones, where the grains are of chamosite, an iron aluminium silicate, and the Abbotsbury Ironstone in Dorset, where they are of the iron oxide limonite. The oxide haematite is also a constituent of some iron ore deposits as for instance those near Ulverston in Lancashire, where the haematite now resting in depressions and cracks in the surface of the Carboniferous Limestone appears to be derived from the once overlying red sandstones.

SALT DEPOSITS. Important beds of rock salt (sodium chloride), anhydrite (calcium sulphate) and gypsum (hydrated calcium sulphate), occur in the Triassic marls of Durham, Worcestershire and Cheshire, the salts having accumulated originally during the drying up of salty desert lakes.

OTHER CHEMICAL DEPOSITS

Other types of salt deposit are locally important, but not in Britain. Such are the famous sodium nitrate beds of the deserts near the coast of Chile.

3. ORGANIC deposits are those formed for the most part from animal and plant remains, but as this material usually decays very easily, it is not very often that it can form thick beds.

In such places as the west of Ireland and in Scotland, deposits of plant debris called PEAT are accumulating in boggy areas with a high rainfall. Peat is also forming in small bogs and fens in the south of England, often under standing water. It is a fibrous material when newly formed, but if it were

crushed by overlying sediments it would have its water squeezed out, and the plant remains would gradually become unrecognisable as such, losing in the course of time all their chemical constituents except carbon.

LIGNITE or BROWN COAL is a stage in this process. It occurs at Bovey Tracey in Devon in small quantity, and in great deposits in Saxony. BITUMINOUS COAL comes next, that is, ordinary household coal, and finally ANTHRACITE, the purest coal, in which there is almost nothing but carbon left. Coal occurs in beds as does any other sedimentary rock, the beds being called SEAMS. You must not imagine that these coals were formed from peats similar to those in present day bogs however. Generally they developed from accumulations of giant woody horsetails in the Carboniferous coal swamps, although some are composed of masses of spores and minute plant fragments that gradually built up in standing water. In the parts of Britain where the coal measures are worked you can sometimes find the fossil remains of these great trees, called *Sigillaria*, and more commonly, pieces of their roots called *Stigmaria*. The descendants of these vast forest trees can be found today in the common horsetails growing little more than a foot in height.

OIL is another organic deposit, slowly built up by anaerobic decay of animal material in bulk (see page 54). The various phosphate deposits also have an organic origin, again from animal remains. The bones of vertebrates are mostly calcium phosphate, hence the famous Ludlow Bone Bed (Upper Silurian) and the Rhaetic Bone Bed (Somerset) which are packed with water-worn teeth, bones, etc., as well as pebbles, necessarily contain phosphorus.

Phosphates also occur in nodules in, for instance, the Gault Clay (Cretaceous) where they may contain ammonites.

Finally, some limestones are essentially organic, especially reef limestones and shell limestones, but these were mentioned briefly with the other calcareous deposits, because most limestones seem to be a mixture of both chemical and organic particles.

4. PYROCLASTIC deposits are those formed from the variously sized fragments hurled out from volcanoes during

violent eruptions. Though not, of course, being formed at the present time in Britain, such rocks were once produced in immense quantities in, for instance, the Lake District during the Ordovician Period.

The largest blocks of lava and pieces of the side of the volcanic vent go to form the coarse deposits called AGGLOMERATES; if smaller pieces predominate they are called VOLCANIC BRECCIAS.

The principal pyroclastic sediments are the ASH BEDS formed from very fine volcanic ash falling into water. This ash may be of separate crystals of rock-forming minerals, or of minute pieces of volcanic glass which have cooled too fast to crystallise. When such ashes become lithified by later infiltration of perhaps, siliceous water, the resulting harder rocks are called TUFFS. Ashes and tuffs behave in much the same way as arenaceous and argillaceous sedimentary rocks of similar grain size and hardness, and may sometimes be mixed with them.

FULLER'S EARTH is a kind of clay derived from volcanic ash deposited in water, the volcanic glass being converted to a clay mineral with a most marked affinity for water and grease, hence its commercial value.

CHAPTER VIII

LAND UPLIFT

WHEN, in an earlier chapter we dealt with erosion it may appear to have been irresistibly destructive. If, in fact, erosion continues for an exceedingly long time, the land surface becomes so worn down as to be almost flat. This flattened surface is called a PENEPLAIN. Once it has formed, land erosion almost ceases, unless circumstances change drastically. There is no doubt that such drastic changes do occur from time to time, as a result of upward or downward movements of pieces of the Earth's crust. You will remember that we think that the Earth's crust is made of granite blocks which are more or less " floating " in the denser basaltic layer underneath. These granite blocks are the bases of the Continents.

Now think of such a continental block being worn down by millions of years of denudation. So much rock material is removed that the total weight of the block is appreciably reduced. As a result the rest of it " bobs up," not immediately, but after some delay whilst the lighter granitic block overcomes the resistance of the surrounding crust. Vertical movements of this kind are called ISOSTATIC.

This leads to the uplift of an area of land which is then ready to be eroded again. The land features which were almost at sea level are raised many thousands of feet, and the river systems begin again to erode vigorously. The mature worn-down landscape is very gently undulating, with wide silted-up valleys, and is in strong contrast to one which has been rejuvenated by land uplift. When this happens the rivers CUT BACK from the sea, eroding particularly fast at a point called the KNICK POINT. (Fig. 13.) This knick point is often a change of slope which is not very easy to see in the field, and

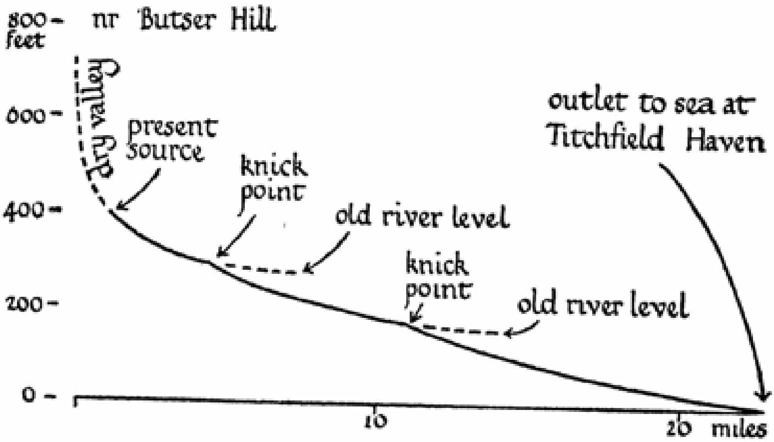


FIG. 13.

Profile of the Meon Valley, Hampshire, to show two knick points, and upper part of valley now dry, though once occupied by the headwaters of the River Meon.

is best shown by drawing a longitudinal section of the valley and then exaggerating the vertical scale. Sometimes it may be marked by a waterfall. In any case, the rejuvenated river runs in a newly-cut gorge inserted in the old valley bottom, a state of affairs often met with in Alpine valleys.

The movements upwards of land blocks as a result of continued erosion can be matched by downwards movements in areas of prolonged sedimentation. The immense weight of thousands of feet of silt accumulating in deep marine hollows, may well cause these hollows to become even deeper. Similarly it seems that during the Pleistocene Ice Age, with a thickness of ice amounting to some 6,000 feet or more, the land surface of Northern Europe was pushed down by about 1,500 feet. The Ice Age is a thing of the past, having started to recede about 25,000 years ago, and the land is now rising again. The part of Europe showing the fastest recovery is at the head of the Gulf of Bothnia in the Baltic, where the land is rising at the rate of about a foot in twenty years.

Other major movements take place in the Earth's crust, a good deal faster than those just mentioned, and sometimes with quite spectacular results. In the first place, any move-

ment between two pieces of crust follows a period during which an immense strain develops between them. Suddenly this strain overcomes the resistance of the rocks joining them together, and the two pieces can move slightly and adjust themselves into new positions. When this happens the sudden movement produces an earthquake. Very often earthquakes occur along definite lines of weakness, and on one side of the line the land may move, for example, northward, and the other towards the south. Alternatively they might move upwards and downwards at various angles. This line is actually a plane, inclined or vertical, and is called a FAULT. Faults are very common in some districts, and can easily be recognised in cliffs and quarries because of the sudden ending of particular rock beds, which start again on the other side of the fault at a different level. (See Fig. 14.)

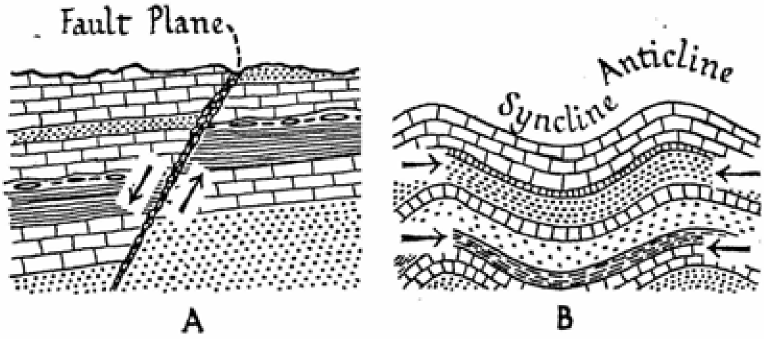


FIG. 14.

Sections through strata to show (A) a fault, and (B) a syncline and anticline. In (A) the arrows show the relative movement on each side of the fault, whilst in (B) they indicate the direction of the pressure responsible for the folding.

The actual plane of the fault is marked by a zone of shattered and crushed rock called the FAULT BRECCIA, the rock fragments often being cemented together with quartz or calcite. Faults may vary tremendously in size, from those with a displacement of as little as a fraction of an inch up to those of many yards. Very big faults do not take place all at once, but by a series of smaller movements in the same direction.

Very strong lateral movements do not always break rock

masses. They may bend (or FOLD) them, although it is less easy at first sight to see how rock beds can actually bend. Very often the rock breaks along a very large number of planes at right angles to the direction of the pressure, then the pieces of rock become pushed into a curved shape (perhaps resembling a train going round a curve in the railway line, each coach representing a section of the rock bed).

Ordinary folds can be of any size, from a few inches across to hundreds of miles, depending upon the amount of pressure, and the type of rock involved. If the fold is like a dome it is called an ANTICLINE, but if it is basin-shaped it is a SYNCLINE. (You can remember which is which by thinking of a Syncline as being something that SINKS in the middle!)

Strong folding may squeeze out softer clays from behind harder beds, and can produce all kinds of contortions in the disturbed strata. If the pressure is prolonged enough, the folded portion may be pushed back again so as to lie horizontally, when it is called a RECUMBENT FOLD (see Fig. 15).

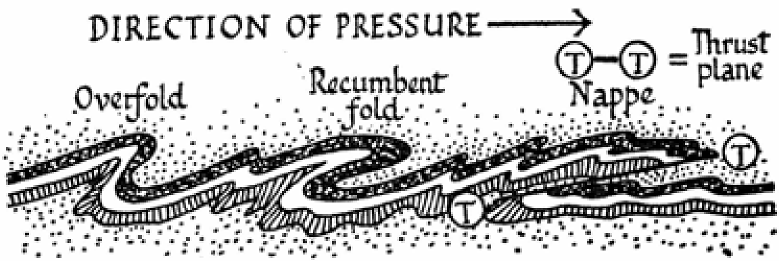


FIG. 15.

Diagram to show how recumbent folds and nappes develop by continued lateral pressure and increasing displacement of rocks.

During very powerful earth movements recumbent folds may be pushed as a whole horizontally, when they break their connections with the beds below and slide over them. This surface of sliding is called a THRUST PLANE. It is really rather like a horizontal fault. You can see a good example of one, though it is rather inaccessible, in the N.W. Highlands, where rocks of the Pre-Cambrian System have been pushed actually over and on top of fossiliferous Cambrian beds along the Moine Thrust Plane.

This type of folding may be so acute that during the folding of the Alps, it can be seen that some pieces of folded rock have been pushed for miles over neighbouring country, completely uprooted from their points of origin. These dislodged portions of rock are called NAPPES, and they give rise to the most complicated rock structures known.

You have probably read in your Geography books of FOLD MOUNTAINS. Sometimes, as may be seen in the Middle East, a single anticline can form a mountain range, which in shape is rather like an upturned boat. Usually however we get a whole series of anticlines and synclines together, and the valleys and hills follow the selective erosion of rivers along the softer beds. We find, rather curiously, that the highest mountains are usually formed from the erosion of synclines, and not from anticlines. Fold mountains are usually of relatively recent geological age, for instance the bulk of the Alpine and Himalayan ranges were formed during the Miocene and Pliocene.

While we are thinking of these immense movements of pieces of the Earth's crust, that have undoubtedly happened during past ages, we may consider some Earth movements which certainly seem to have happened, although some geologists do not believe it possible. These movements have involved the horizontal shifting of whole continents, that is, the separating of pieces of the granitic continental blocks, which have "floated" apart on the underlying basaltic layers. If you look at a map of the World you will probably notice that if you were to cut out the outline of S. America, it would fit fairly well if you slid it across to meet S.W. Africa! This alone has seemed to some geologists to amount to almost certain proof of CONTINENTAL DRIFT (as it is called) but it is not quite so simple as this. We must remember to allow for the parts of the continents submerged by the present seas. If we draw the outlines at the edge of the Continental Shelf, however, the shapes are still complementary, and there is also very close similarity in the detailed geology of the two continents, the strata and folds in one match the strata and folds in the other.

Again, it seems that during the Carboniferous Period there was an Ice Age in S. America, S. Africa, India, Australia and Antarctica, and that during the Permian Period similar rocks

were being deposited in all these countries, containing the same fossils. It seems to me that quite the easiest way of explaining these similarities, is to assume that from about the Silurian Period to the Jurassic Period all these continents were clustered together into one giant continent, which has subsequently come into pieces which have drifted apart.

Similarly, N. America, Europe and N. Asia were collected together to form another continental mass, but this too has suffered the same process. Incidentally, Europe and N. America are still drifting apart, but so slowly that there is no danger of it disturbing our maps for a very long time to come.

CHAPTER IX

GLACIATION

GLACIATION may be defined as the result of an area of land being covered by a very thick ice sheet or by moving glaciers.

Its importance in Britain lies in the fact that the last major event in the geological history of Britain was the Pleistocene Ice Age. In this period (which ended very approximately 20,000 years ago), few parts of the country remained completely unaffected by glaciation. Over great areas the soil now covering the countryside is wholly derived from glacial sands and clays known as DRIFT. In the hilly districts many of the valleys owe their shape almost entirely to glacial action.

Apart from its weight, ice that is stationary has no effect on the rock beneath it and may well preserve it, but when the ice moves, its power to erode (or grind the surface), is considerable. Because of this we must look at those areas where ice is still moving in quantity if we wish to discover how it can wear down the rocks on which it rests. At the present time snow can accumulate in Europe only on the highest mountains above the "snow-line." Below this level the snow always melts in the summer, and as one proceeds towards the North Pole, the snow-line becomes lower and lower until finally snow and ice are found at sea level throughout the year. Above the snow-line each year's snowfall is added to existing deposits, and gradually the mass thickens and its deeper layers are compressed into ice. A certain amount melts during the summer, and a little evaporates, but if the supply of new snow is excessive, the surplus escapes as moving ice at the margins of the areas where snow and ice have accumulated.

We find many places in the Alps and Norway, for instance,

where icefields occur at high levels, and glaciers transport the surplus ice from the margins of the icefields to lower altitudes. These glaciers may drop steeply over more or less vertical cliffs, or extend for several miles along valleys.

A considerable amount is known about the ways in which glaciers erode, but less, unfortunately, about the enormous ice-sheets of the Continental type, at present only to be seen covering the whole of Greenland and Antarctica. These ice-sheets may be of immense depth, thus the Greenland ice is about 10,000 feet, or nearly two miles thick! The surplus ice escapes, either as glaciers between the mountains fringing the icefields, or along a broad front such as the Great Ross Barrier of Antarctica, where the ice-sheet floats upon the Ross Sea with cliffs of ice over 100 feet high.

During the Pleistocene Ice Age similar ice-sheets covered both N.W. Europe and much of N. America, leaving great expanses of debris.

We can discover a little about the inside of a glacier by digging tunnels into the ice, and also by various experiments. At depths greater than about 200 feet, the ice in a glacier behaves rather like a liquid. This is because the weight of the overlying material causes the ice at the points of greatest pressure to melt momentarily to water, which acts as a lubricant and allows the piece above to slide down over the piece below. Immediately the pressure is relieved, the water refreezes.

Another way of getting information is to examine the characteristic marks and debris left behind when a glacier melts. At present, most glaciers are getting steadily shorter, or are "retreating." This is because, with the gradual warming due to change of climate, there is no longer sufficient snow falling on the mountains to balance the loss due to the melting at the margins.

In the mountains, a valley glacier receives at its two sides a continuous shower of stones of all sizes falling from the steep slopes above. Together with fragments of rock broken off at the edge of the valley, these constitute the LATERAL MORAINES, moraine being the name given to the masses of rock debris eroded and carried along by a glacier. When the glacier melts, these moraines will be left as two steep sloped ridges of stones,

one along each side of the valley. Innumerable stones are carried actually within the ice of the glacier, some gradually sinking in from the top, and others which are caught up from the valley floor. At the front or "snout" of the glacier, where melting overtakes supply, these enclosed rocks will be released, and will accumulate to form a TERMINAL MORAINE. This moraine is crescent shaped when well developed. Sometimes a temporary re-advance of a glacier will cause the glacier tip or snout to push the terminal moraine forwards, as would a bulldozer. This makes the crescent-shape even clearer.

The rock fragments composing the moraines which are being formed at the present day in the Alps show an astonishing variety of different sizes, ranging from the very finest powdered rock, called ROCK FLOUR, to enormous boulders as large as a house, and all thoroughly mixed together. In addition, the moraines contain masses of ice buried far inside. When these masses slowly melt, internal cavities are caused and the subsequent collapse of the roof of each cavity leads to deep conical depressions on the moraine surface.

The enormous strength of a glacier may be realised when we stand upon this type of moraine, perhaps several hundred feet high and a mile or so long, and consider the strangely disordered piles of stones extending away out of sight up the valley.

In Germany there are Pleistocene terminal moraines several hundred miles long. Quite apart from their much greater size these moraines had a rather different origin from the smaller terminal ones described above.

The great Pleistocene glaciers which flowed northwards from the Alps joined together on the low ground to the north of the mountains, producing wide expanses of ice, at whose northern edges the terminal moraines were formed. When several glaciers unite on flat ground in this way we have what is termed a PIEDMONT GLACIER.

You will recall that the ice of a glacier contains numerous enclosed rocks which are gradually sinking downwards, and in addition countless stones which get caught up in the ice from the valley floor. If more fragments accumulate than can be carried, they will be deposited in a confused layer underneath the glacier, called GROUND MORAINE. When the ground

moraine contains much clay the deposit is known as BOULDER CLAY. Sometimes this debris may be shaped by the ice moving over it to produce rounded mounds called DRUMLINS, perhaps about 50 to 100 feet high. These are whale-backed hillocks, with their steep ends facing up-valley (Fig. 16). Drumlins form

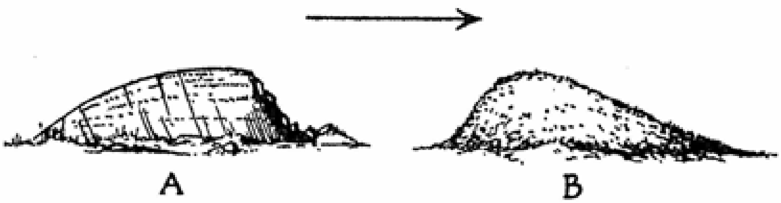


FIG. 16.

(A) Roche moutonnée (B) Drumlin

The arrow shows the direction of ice movement.

conspicuous features of the landscape in parts of Ireland, the Solway and Eden Valleys and the central Lowlands of Scotland.

The rocks enclosed in the glacial ice are the main cause of glacial erosion, for, embedded in the ice, they enable the glacier to behave like an enormous file, wearing and grinding the rock surfaces and tearing out loosened fragments. In this way glaciers considerably deepen their valleys in the solid rock, converting them from the V-section of the pre-glacial river valley, to the U-section of the glaciated valley. U-sectioned valleys are to be seen in many parts of N. Wales, the Lake District and Scotland, as well as in the great mountain ranges of Europe. The grinding of the valley floor produces characteristic rock forms, in particular smoothed slabs, often with grooves or scratches (caused by the hard rocks in the ice) which show the direction of movement in the ice.

Another rock form is the ROCHE MOUTONNÉE, resulting from partial smoothing of particularly hard rock outcrops. Roches moutonnées face in the opposite direction to drumlins, with their steep ends pointing down-valley, and they are composed of solid rock, whereas drumlins are made of gravel and loose stones.

The valley glacier when eroding vigorously, will straighten

the earlier water-worn valley, cutting off its projecting spurs as it develops the glaciated U-section. These are then known as TRUNCATED SPURS. Another interesting and often spectacular effect of glaciation may be seen in the tributary valleys to a main valley containing a glacier. Each smaller lateral valley might contain a small glacier, or possess a small river instead, but in either case erosion could not proceed lower than the surface of the ice in the main valley. If the main glacier were for instance 300 feet thick, then the floor of such a lateral valley would stand 300 feet above the floor of the main valley, unless of course it had already been eroded to a lower level than this before the appearance of the larger valley glacier.

These tributary valleys would then become HANGING VALLEYS in respect to the main valley, and may usually be detected because the present streams drop in long waterfalls into the main valley. Plate 5A, B and C show photographs of a model that I have made of a mountain valley before, during and after glaciation to demonstrate the profound changes that can follow from glacial erosion.

Sometimes a glacier may scoop out its floor below the general level into an elongated basin, especially after being joined by a large tributary glacier. This "overdeepening" is the result of the increased erosion due to the extra quantity of ice. When this has happened and the ice has subsequently melted, we can see the rock basin filled with water, as for instance, Lake Windermere and the Norwegian fjords. These latter may be as much as 4,000 feet deep, but very shallow at the seaward end.

Overdeepening can lead to a series of rock basins, one below another, giving a staircase effect in a well developed glacial valley. Cut into the mountain sides at the heads of these valleys we often find semi-circular depressions called CORRIES, CWMS or CIRQUES in Scotland, Wales and France respectively (Fig. 17). These usually have vertical crags at their heads, which are continuously eroding as ice forms and melts in the rock fissures. Pieces are gradually loosened, and these, on falling into the corrie below produce piles of loose stone known as scree below the crags. When, as in the Alps, corries are still filled with ice, erosion of the crags can also occur through

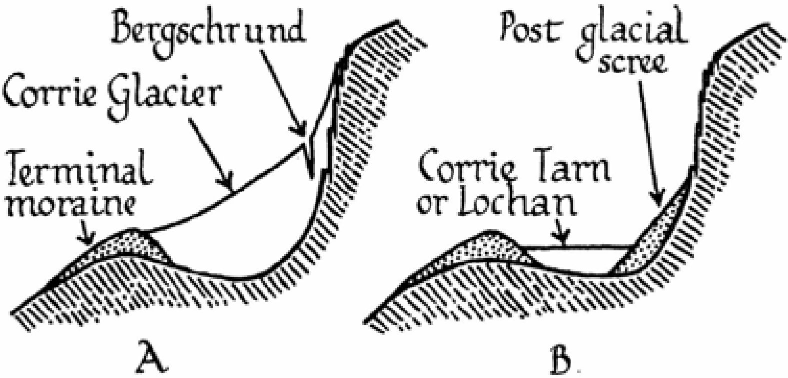


FIG. 17.

Sections through mountain corrie (or cirque) to show:

(A) Conditions in late glacial times with small corrie glacier, and (B) Conditions at present day with tarn partly in hollowed rock basin and partly dammed by moraine.

the ice continually pulling away from the rock face as it moves down into the corrie. This downward movement of the corrie ice (which may in fact be the source of a glacier) often produces cracks in the ice just below the crag. When a particularly clear crack develops it is called a BERGSCHRUND.

We find that glaciated scenery is smoothed and rounded, both as far as the solid rocks and the morainic deposits are concerned, but the appearance of the high mountains that have always projected above the ice, is strikingly different. These mountains are known by their Eskimo name of NUNATAKS. If they were so high as to escape the Pleistocene glaciation, and acted as glacier sources rather than being overrun by moving ice, their outlines will be rugged with many crags and rock pinnacles. Wind and frost will be the causes of erosion, breaking up the rocks according to their principal fissures and planes of weakness. Photographs of the coast of Greenland and parts of Antarctica show such mountains projecting above more or less level ice fields, whilst nearer home we may see similar examples in the Higher Alps.

The Pleistocene Ice Sheet was sufficiently large to pass over the summits of most of the British mountains which consequently have modified outlines, resembling huge roches

moutonnées. Many of their corries have been caused by subsequent and less intense glaciation, when these mountains acted as sources for local glaciers towards the end of the Pleistocene Period.

So far we have been concerned with the deposits and forms of a landscape following the erosion by valley glaciers from high level ice caps, but there remain the effects of glaciation on the scale of the continental ice fields that covered much of Europe during the Pleistocene.

The extensive spreads of Boulder Clay found, for instance, in East Anglia, were derived from the melting of great expanses of ice floating in shallow water. This floating ice was the south-westerly extension of the Scandinavian ice field which at the maximum period of glaciation extended southwards into central Germany, and south-eastwards to the Carpathians and the Ukraine. The ice at its deepest was probably as much as a mile and a half thick, but thinner towards its edges. Successive movements of this ice left considerable thicknesses of drift in East Anglia, made of a mixture of material derived from the bottom of the North Sea, and picked up by ice running aground together with certain far travelled rocks transported from Norway.

The Boulder Clay contains great numbers of flints embedded in stiff clay, but in some places it may contain much chalk, or again the drift may be very sandy. Rocks, such as those from Norway just mentioned, which have been carried great distances by moving ice, are called Glacial Erratics. In East Anglia these may be found as worn pebbles of schist or porphry, whilst in other parts of the country such as the Pennines, one may meet sizeable boulders of Shap granite or Silurian grit, now stranded on, for example, Carboniferous Limestone.

In addition to these morainic and drift deposits which were formed directly in contact with the ice itself, there were spreads of gravel caused by rivers flowing from the melting front of the Pleistocene Ice Sheet, which did not advance further south than the Thames valley, and also from snow capped hills near to the ice front. These so-called "periglacial" deposits are now represented in Britain by various gravels often at relatively high levels, such as the Plateau

Gravels of southern England. These are specially well developed on the Tertiary sands, where they form protective caps to the hills of Bagshot sand. These gravels are mostly made of flint but some contain chert from the Lower Greensand of the Weald.

I know two little boys who are ardent geologists. Their leisure is spent in grovelling among the hillocks of the Plateau Gravel which overly the Bagshot sand of the Berkshire heathland. They have their own museum, containing a surprising collection of excellent fossils (sea-urchins, sponges, etc.), derived from the chalk and carried north by the Pleistocene rivers (long since vanished) which rose in the hills of the Weald.

CHAPTER X

SOILS

APART from those places where hard rocks are directly exposed (very few in the south of England though much more frequently in the mountains of Wales and the north), the whole country is covered by a layer of soil. This soil complicates the task of the field geologist who is often unable to tell where one rock outcrop begins and another ends. I have often thought how beautifully simple it could be if all the soil could be miraculously removed one day; we could then see the rocks as clearly as on a geological survey map, though not perhaps so colourfully. Realising that we cannot remove this soil over large areas, we must learn to make use of it in helping us to decide what rock lies underneath.

You may think that it is quite easy to say what soil is, but all sorts of problems appear when we try to describe it. How far down should we go? Have you ever thought how *deep* soil may be and what there is underneath it?

If you think of soil being formed from the underlying rocks by weathering, you will understand it better, and will see why the soils on, say, chalk downs are different from the soils on the red clays of the Midlands. This is because the parent rocks are so different to start with, although this is not the whole explanation, because the very plants that grow in the soil are capable of altering its make-up quite considerably.

As the parent rock breaks up into small pieces, and becomes chemically weathered, generally being oxidised to a rusty brown, a certain amount of clay is produced too (even from a non-clayey parent rock), which will often fill in the gaps between the much more stable quartz grains. The only plants that can grow on a bare surface of an exposed igneous rock

(providing that they have some moisture) are lichens, followed by a very few species of moss, though of course many other plants can establish themselves as soon as there is some soft clay material in which to root. Their dead leaves and stems collect on the ground surface where they rot and produce the minute black or brown particles of carbonaceous matter called HUMUS, which gets washed down by rain into the deeper layers of soil. And do not forget the good work that earthworms do in producing fresh soil, you have probably seen a leaf sticking half out of your lawn, dragged into an earthworm's burrow to form its next meal. It will then eject the inorganic matter in the form of "worm castings."

This final mixture of weathered rock and plant remains is really the soil as we know it. It will obviously be laid down in horizontal layers which will change from the unaltered rock at the bottom to leaf mould and plant debris at the top. This layered structure, as we can see, for example, in the sides of a newly dug trench, is called a SOIL PROFILE. You will see that the development of these orderly layers can only happen in a NATURAL soil, that is, in one that is not being continually cultivated. One of the aims of ploughing land is to mix up these soil layers very thoroughly, so we cannot hope to find a good soil profile in arable land.

You will also see that a physically hard rock will disintegrate and produce a soil much more slowly than a soft rock such as a sedimentary clay. The soil on the former may be only an inch or two thick, but on the latter may be several feet deep, and will merge gradually downwards without any clear point where we can say that the soil ends and the rock begins. You will remember though, that some of the minerals in an igneous rock break down chemically, and in damp hot climates a hard granite may weather so profoundly as to give a soil as much as 30 feet deep, this happens, you will recall, in Malaya.

The very best type of soil profile for you to examine is the so-called PODSOL, which is so common on the Tertiary sand of Surrey, on the glacial sands and gravels in East Anglia and on so many glacial deposits in the north of the country where the rainfall is high. The word Podsol is derived from a Russian word meaning grey or ashy, and refers to the greyish or white upper layer of sand, each grain of which has had its

enclosing brown layer of limonite dissolved off by the rainwater. You will already be quite familiar with this loose white sand on paths and tracks.

The podsol profile develops in porous (non-clayey) soils, because rainwater which is already slightly acidic, becomes more acid still when it reaches the soil, through the addition of organic acids produced from the decay of plant remains. This acid solution runs down into the soil, dissolving the soluble salts necessary for plant growth. The last substance to be dissolved is the yellowish brown iron oxide sheath covering each sand grain, so that when that has gone and the grains are colourless we can be sure that everything else has gone too. Of course these substances cannot run downwards indefinitely. They are deposited in accumulation layers some

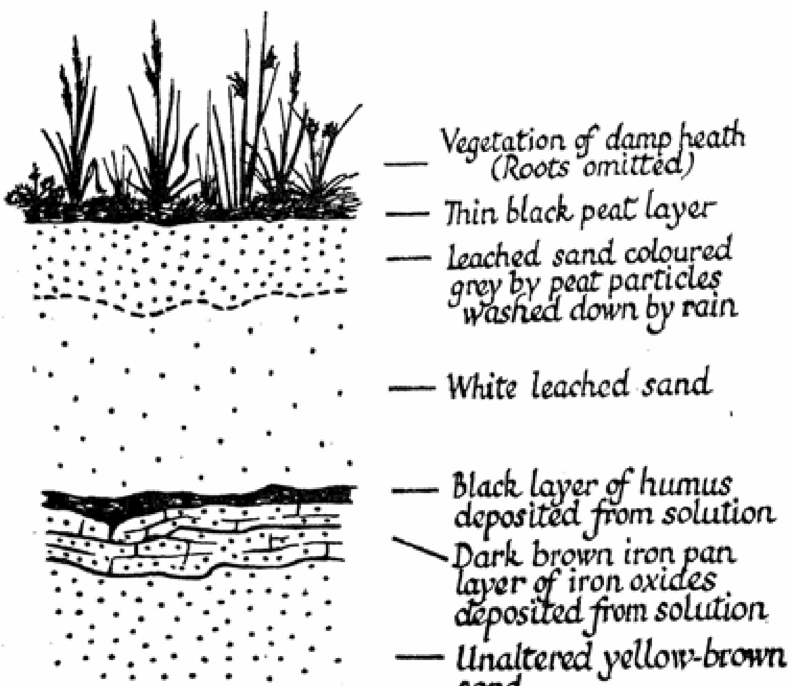


FIG. 18.

Soil profile showing a well-developed Podsol. The iron-pan layer would be about two feet below ground level.

feet below the surface, the humus in a black layer and the iron in a dark brown layer (see Fig. 18).

As a Podsol profile develops the upper part of the soil becomes poorer and poorer, and ultimately becomes unfit for cultivation. Such land normally bears heathland vegetation, or perhaps pine or birch woodland. In some places so much iron may be deposited in the iron accumulation layer that it forms a hard band of iron stone called the Iron Pan, which may be several inches thick. In fact it may become so thick as to prevent water running through it, water-logging the soil above and leading to conditions wherein only bog plants can grow.

Soils derived from iron-rich limestones (as for example, the yellow Jurassic limestone of the Cotswolds), do not become acid and never develop into Podsols. There is always a considerable amount of lime in these soils, which are usually reddish brown and rather clayey; such a soil is called a Brown Earth, and is very productive for the farmer. Many deciduous woodlands develop a type of Brown Earth soil profile too, because trees such as oaks root much deeper than the shallow rooted pines and birches. The oaks can draw upon the soluble minerals deeper in the soil, and later return them to the soil surface in the dead leaves. These leaves rot relatively quickly to give a good leaf mould, as opposed to the very slow decomposition of conifer needles which produce substances harmful to plant growth at the same time. (No doubt you have noticed the lack of undergrowth in a pinewood).

In the Brown Earth there is a continuous cycle of substances from the surface downwards and then back to the top via the decomposing plants. In the Podsol it is a one-way process, ever downwards (Fig. 19).

Of course there are many other types of soil that you will come across, Podsols and Brown Earths are only two of the most important, most of the productive agricultural soils of this country being ploughed up Brown Earths. There are numerous intermediate soil types, and also some special ones. Thus in the Fens of East Anglia great quantities of peat have formed in alkaline water, and when such areas are drained the peat shrinks so much as the water comes out, that the land level falls by several feet. This black peaty soil is ex-

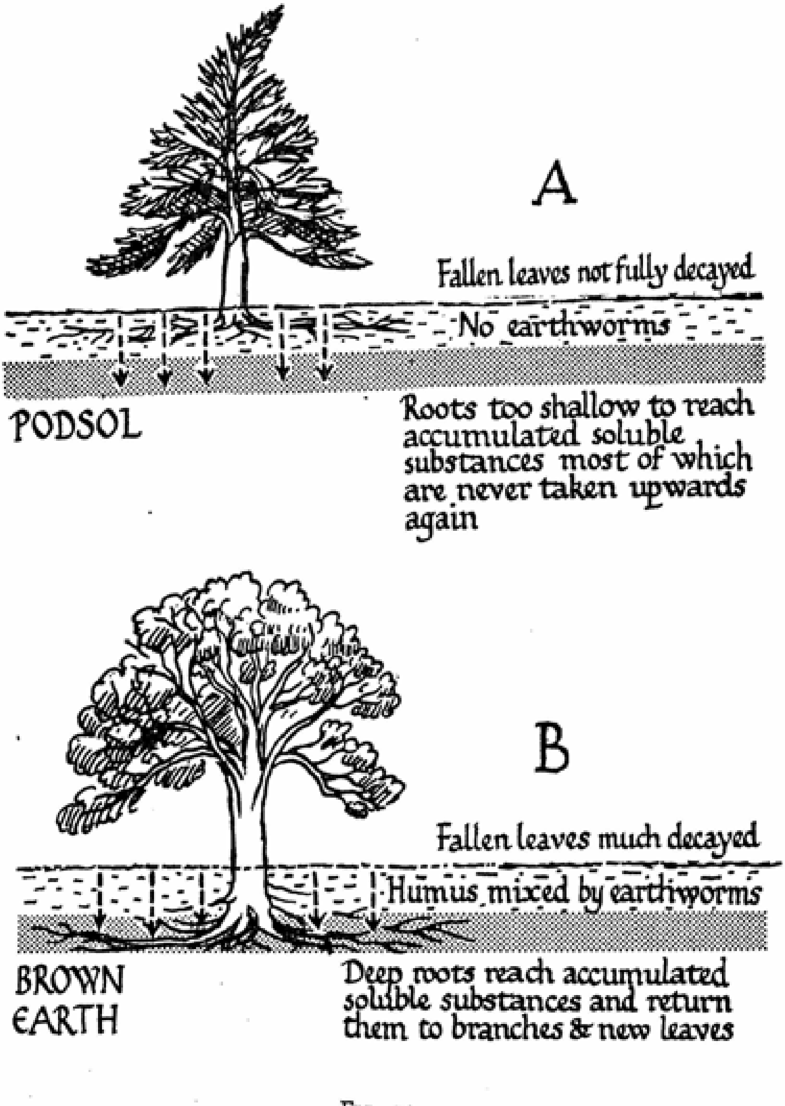


FIG. 19.

Diagrams to show how (A) a poor podsol profile develops under shallow-rooted conifers, but (B) a richer brown earth under deep-rooted deciduous trees such as oaks. The chemical accumulation zone is stippled. (Not to scale.)

tremely rich for plant growth, quite unlike the acidic peaty soils of, say, the Pennines. Draining mountain bogs merely produces extremely acid soil conditions, and very little can grow there.

In those soils which have been derived directly from the underlying rock, one can often identify the rock by examining loose stones either on the surface or in such places as molehills or rabbit burrows, assuming of course that there are any rabbits left in your district! But over much of the country the soil is not derived directly from the solid rock, but from the so-called "superficial" deposits. These may be, for instance, alluvial silts or the gravels of river terraces produced in the river valleys, or they may be the widespread and infinitely variable sands, clays, and gravels of the glacial drift. Here the rock particles will have come from other parts, perhaps from a distance of many hundreds of miles

However our soil is derived, whether from the parent solid rock directly, or from superficial deposits, we can get a good deal of information about it by observing the plants that grow upon it. I have found that being a botanist has helped me considerably when searching for the outcrops of different rocks. A particularly good example of this occurred when I was on a geological field excursion in South Wales, and was given the task of mapping the junction between two rock outcrops, one a limestone and the other a sandstone, both of the Carboniferous age. I was able to detect the line of junction for much of its length owing to the fact that on one side grew the lime-loving hardrush (*Juncus inflexus*) but on the other side it was replaced by the less lime-tolerant softrush (*Juncus effusus*).

A soil type that can be very misleading to the geologist using plants as a guide to the rocks beneath, is the so-called Clay-with-Flints on the chalk downs. This is slightly acid, and represents the accumulation over a vast number of years of the clay and iron oxide particles from the chalk. Bit by bit the lime is dissolved away, and very slowly the residue builds up. It supports generally an oakwood vegetation when undisturbed, and is notable because of the absence of typical lime-loving plants.

The soils developed from glacial deposits have no connection in any way with the solid rocks directly underneath, and in

areas where glacial deposits are extensive it is far better to use one of the "DRIFT" maps of the Geological Survey, rather than a "SOLID" sheet.

There is one further warning that I must give concerning the use of "plant indicators." You may find lime-loving plants growing by streams high in igneous mountain districts, where there cannot possibly be any limestone. This is because there may be much lime (calcium) being freed by the chemical decomposition of, for instance, a basaltic lava, even though there is no free calcium carbonate, and hence no fizzing if you were to add a drop or two of dilute hydrochloric acid to the rock. Again, I know of a flourishing mass of traveller's joy (*Clematis vitalba*) a chalk indicator, growing apparently on a stretch of acid Bagshot sand. But closer investigation shows that it is growing over the remains of a broken-down wall, from which the dissolving mortar presumably gives its necessary lime.

If you are not familiar with the various plants that can be used as geological indicators, I advise you to consult a flora, and also to join any local Natural History Society where you will, in all probability be able to get help from competent botanists. If you possibly can I also advise you to join the Botanical Society of the British Isles, and if you live near to London, join the London Natural History Society which organises both geological and botanical outings. The Field Studies Council also runs courses in these subjects at their four Field Centres at Flatford Mill (Essex), Juniper Hall (near Dorking) Malham (Yorkshire Pennines) and at Dale Fort (Pembrokeshire). I can assure you that you cannot have any better training in Field Studies than at these delightful Centres.*

* Since this was written, the Field Studies Council has announced the opening of a new Centre at Preston Montford in Shropshire.

CHAPTER XI

FOSSILS

HUNTING for fossils is one of the main joys of the field geologist. In districts where they are few and far between, the successful collector has the satisfaction of having found a rarity, whilst in areas where they are much more numerous he may then concentrate on finding the most perfect specimens.

I have recently been geologising by the side of the Fleet in Dorset, and I must admit that it is a delight to find stretches along the shore where it is difficult not to walk on the brachiopod *Rhynchonella,* and to see banks almost solid with the slender shells of the oyster, *Ostrea hebridica.*

Quite apart from the simple pleasures of fossil hunting, the study of fossils, or PALAEONTOLOGY as it is called, is of tremendous importance both to the geologist who wishes to determine the age of rocks and to identify strata, and to the biologist who is studying plant and animal evolution.

First of all, what is a FOSSIL? It is the hard and usually petrified remains of a plant or animal which lived in earlier ages and, resisting decay, has become buried in the ground by natural agencies. We must include the imprints of shells etc., and of animal footprints, also the marks made, for instance, by rain drops, and ripples in shallow water in the distant past. Most fossils are animal in origin, but not all animals would make good fossils, because the softer they are the less likely they are to leave permanent impressions on the sediments in which they lay. (Nevertheless it is a fact that some of the very oldest fossils ever found, dating back to Pre-Cambrian days, more than 500,000,000 years ago, are the imprints of animals with as little substance as jellyfish.)

The best moulds or casts of fossils are those of organisms

with hard shells or bones. In these, the soft parts will rot away usually without trace, but the bony or shelly matter will be preserved intact, perhaps with no more change than a certain amount of internal recrystallization.

The longer a fossil has been in a rock, the more profound will be the changes it has undergone. The very oldest specimens may be so completely recrystallized as to have lost most of their original structure. A very common type of fossilization is that in which the minute pores or internal cavities (such as the cells of a piece of wood), may be filled with some substance such as iron pyrites. Coniferous wood fossilizes this way and is common in some clay formations, including the Wealden beds of the Isle of Wight and the London Clay of the Isle of Sheppey.

Sometimes this replacement is so minutely perfect that every detail of the original cellular structure is still visible. I have collected numerous pieces of fossil wood which bear examination with a microscope almost as well as a section of a present day timber. When this happens the cellulose cell walls have not suffered much change during fossilization, it is only the cell cavities that have become filled up. Similarly we find that the phosphatic material in bones is exceedingly stable, so too is the chitinous exoskeleton of many arthropods. The chitinous "shells" of some Cambrian trilobites have lasted in a recognisable condition for possibly 500,000,000 years.

On a larger scale, the internal chambers of Jurassic ammonites may be filled with calcite, and the cavity within a Cretaceous sea-urchin with silica.

Most frequently, when an organism dies and its soft parts decay, the space inside it becomes filled with fine mud particles. Next, especially in sandy formations, after consolidation of the rock, acidic water running down dissolves away any calcareous matter in the shell, leaving a space of the exact shape of the original shell. Alternatively the calcareous shell may be replaced, molecule by molecule, by silica ending up as a siliceous replica. Although most animal fossils are calcareous to start with, they may be replaced by many minerals other than silica, depending upon local conditions.

The cavity left in a rock when a complete fossil is removed

is called an IMPRESSION or MOULD, whilst the material filling the internal cavity of a hollow organism will, when exposed by removal of the skeletal matter form an internal CAST. This is shown diagramatically in Fig. 20.

A good IMPRINT (impression) is certainly worth collecting, especially if you cannot find a solid specimen of the fossil that made it. A group of imprints of a rather different origin are those foot-prints left in soft mud by a wandering dinosaur. These are sometimes to be found and they help us to understand what a dinosaur's foot was like when it had some flesh on its bones. (But one can hardly applaud the advertiser in an American newspaper who offered recently, " 200,000,000 year old Xmas gifts for Moderns. Curious, fascinating, rare Dinosaur Track Conversational Pieces in door steps, fireplaces, paths, paper weights and book ends, from the only area in the world where authentic tracks are excavated. Are very unique.")

Different again are those imprints left in mud by large scattered raindrops, little craters with raised rims. With these we can group the cracks in similar mud which has dried, such as those photographed (Plate 6B) which I found on some extensive flows of Liassic clay on Black Ven near Charmouth in Dorset. The cracks might become filled with a sediment differing perhaps in colour, and then on consolidation we would have the original drying cracks preserved as a coloured polygonal pattern.

I have collected specimens of Devonian flagstones from Pembroke which show such markings, others show the remains of ripples caused by small waves in shallow water covering the sand before it was lithified, maybe 300,000,000 years ago.

Fossils are often found in the centre of concretions of various types. Sometimes the original shell rolled about on a clayey floor and gradually built a ball of clay around itself. During the process of fossilization the nodule becomes harder as it loses water, and may crack, the cracks perhaps being gradually filled with calcite. At other times certain minerals will migrate through the rock and crystallize out round a fossil. In such cases as these, the fossil will be preserved in its original form, and may be revealed in good condition on cracking open the nodule.

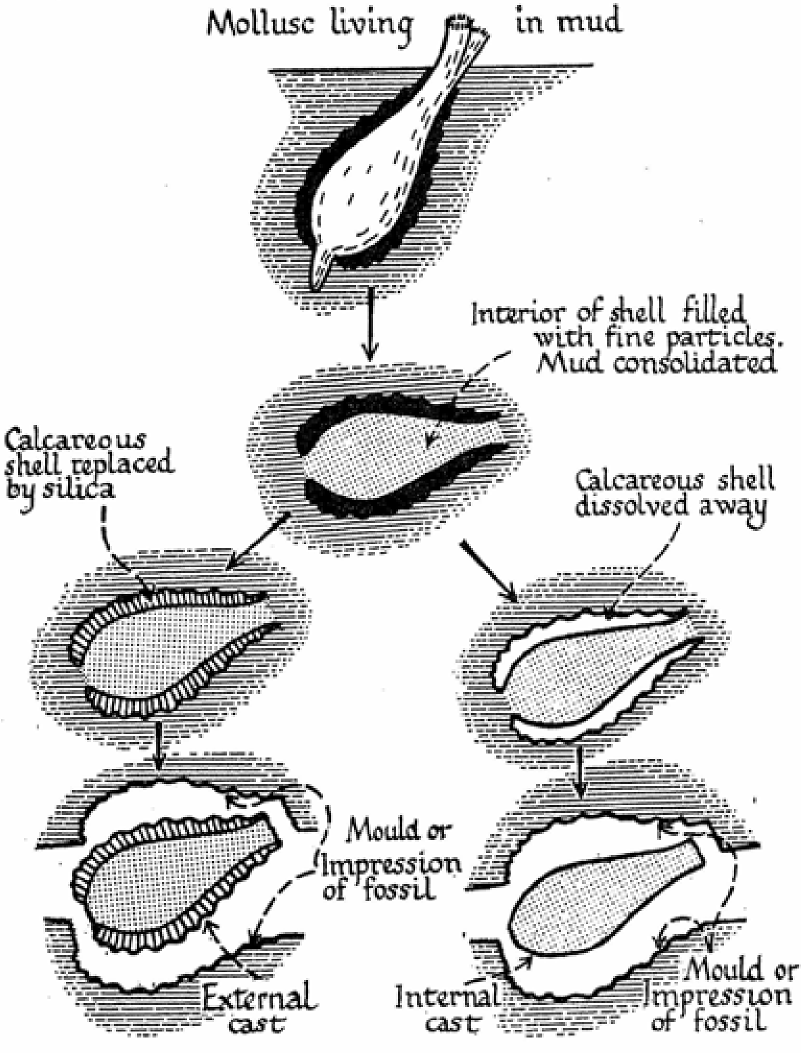


Fig. 20.

Some ways in which fossils can be formed.

Most fossils have always been in the particular rock in which you find them, but sometimes they may have come from earlier deposits and have been incorporated into later sediments. Fossils of this kind, usually water-worn and rounded, are called DERIVED FOSSILS because they are derived from rocks of an earlier age. The most common examples are tough objects such as pieces or bone (often found in vast numbers in some beds called BONE BEDS), belemnite " guards," and the thick shells of molluscs such as oysters. A good example of a derived fossil is a rather battered Jurassic belemnite which I found in some Pleistocene Boulder Clay from Sheringham in Norfolk. Pebbles also can be derived from earlier formations, thus many stones in the Triassic pebble bed at Budleigh Salterton in Devon probably had their origin in Ordovician strata in France. Incidentally, these same pebbles are now being washed along the coast and are being incorporated in a present day deposit, the Chesil Bank in Dorset. Thus these pebbles are " derived " for a second time.

The geologist attaches the greatest importance to fossils. Undoubtedly the best way of correlating rocks of the same age in different parts of the country is by a careful study of their fossils.

This is explained by the fact that each rock formation has its own characteristic set of fossils which differ from those of both earlier and later rocks formed at the same time in other districts.

It sometimes happens, especially if a genus of animals is evolving rapidly, that each species in the succession may have lived for only a relatively short time, and is consequently found only in a small thickness of rock, possibly no more than a foot or so deep. Thus, if a clay in Surrey and a sandstone in Cambridgeshire both contain a certain species of short-lived ammonite, we can be sure that they were formed at the same time. Fossils with a short time-range are far better for identifying strata than those with a long time range (Fig. 21), but they should also have a wide geographical spread to be helpful on a large scale. Some fairly rapidly evolving groups such as the graptolites, ammonites and *Foraminifera* also floated free in the surface waters of the seas, and so were able to spread over considerable distances. This, coupled with

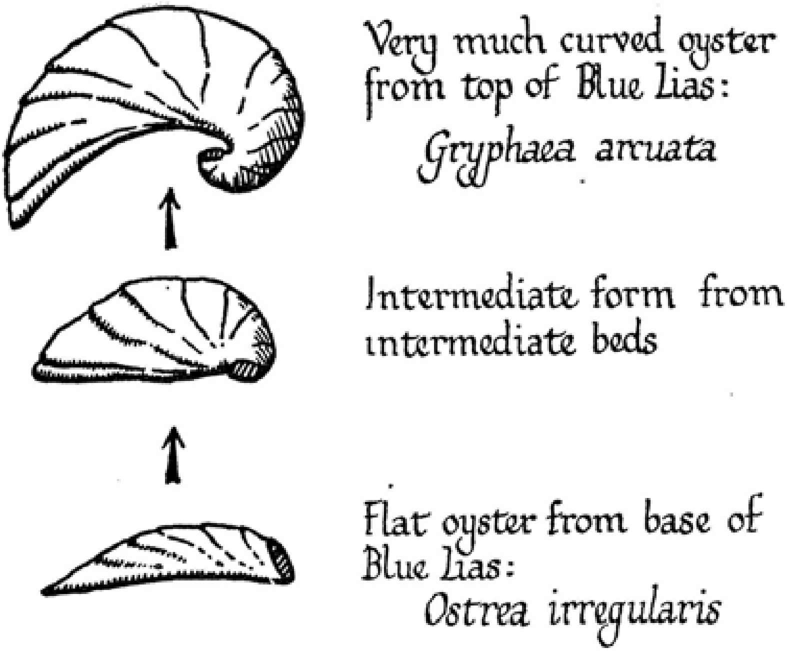


FIG. 21.
Evolution in some Jurassic oysters.

the short time that any particular species lasted before it evolved into a new form makes these groups the most useful of all for correlating rocks in different places. Sometimes, though, we have to use sedentary creatures like corals or molluscs that live in holes in mud, but they are usually less satisfactory. Sometimes, too, one has to use the whole assemblage of fossils occurring in a rock, treating its fauna as a whole, but whenever it is possible it is much better to select a short range fossil, confined to a narrow thickness of rock and to call this thickness the ZONE of the fossil in question. Thus, the Gault Clay and Upper Greensand formations are divided into five Zones which are named after five characteristic Zone fossils (in this case they are all ammonites). These Zones are:

Stoliczkaia dispar. Zone
Pervinquieria inflata Zone
Euhoplites lautus Zone
Hoplites dentatus Zone
Douvilleiceras mammillatum Zone.

Each Zone is then further sub-divided into Sub-zones, again named after particular species of fossil, referred to by the specific name of the fossil. Thus, a Sub-zone of the *Hoplites dentatus* Zone is called the *intermedius* Sub-zone after its characteristic fossil *Anahoplites intermedius.*

It may be useful to list the main types of fossils used for zoning and correlating of different strata, but there is not the space here for detailed zoological descriptions of the different animal groups. For this you should read a book devoted to Palaeontology.

Fossils used for zoning (see illustrations in Fig. 22):

Tertiary	nummulites (Foraminifera) lamellibranchs, gastropods
Cretaceous	Sea urchins, belemnites, ammonites brachiopods
Jurassic	ostracods (freshwater beds) ammonites almost entirely. Some brachiopods and lamellibranchs
Triassic	ammonites
Permian	plants, etc.
Upper Carboniferous	plants, freshwater mussels
Millstone Grit ...	plants, goniatites
Carboniferous Limestone	corals, brachiopods and goniatites
Devonian	goniatites. fishes and numerous plants
Silurian	graptolites, brachiopods
Ordovician ...	graptolites, brachiopods, trilobites
Cambrian	trilobites, graptolites, brachiopods

The use of fossils to the evolutionists is at once obvious. Whereas we can argue for years as to which animals or plants evolved from which, and which are therefore primitive, and which are advanced, it is only by examining fossils that we can get absolute proof of the route that evolution actually

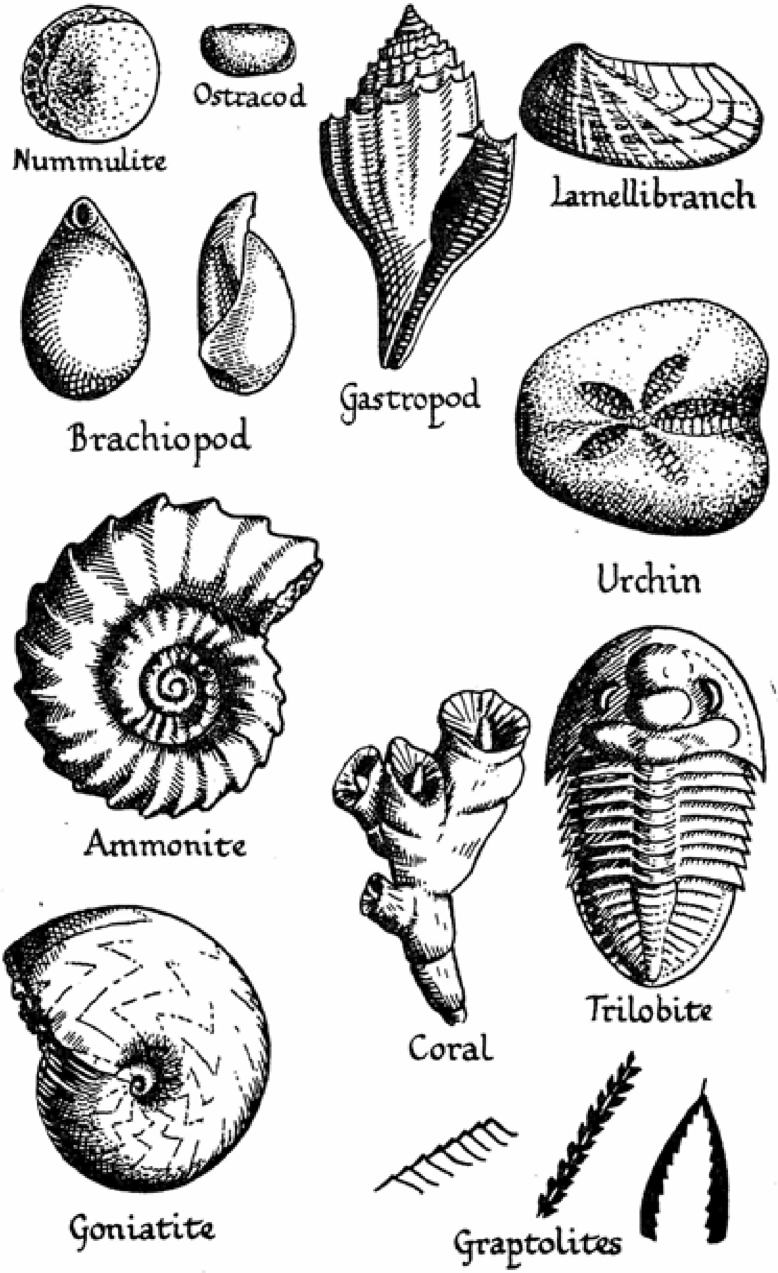


Fig. 22.
Various fossils.

took. A supreme example of this is the belief, held until quite recently, that Man has evolved from apes. This has been finally disproved by the discovery in South Africa of fossils called *Proconsul,* from the Miocene. These combine the characters of Man and ape in a curious way, and yet are not in any single character as extreme in form as either. Obviously both Man and anthropoid apes had common ancestors in the Miocene, and one cannot possibly be derived from the other.

You will see from what has been said earlier in this chapter that you should always keep a record of where you find every fossil, and if you refer to Chapter I you will find that I have given you further advice on collecting.

CHAPTER XII

GEOLOGICAL MAPS

IN the first chapter of this book I advised you to consult geological maps whenever possible. (A simplified map of the British Isles is shown in Fig. 23). I should now explain further that "consulting" a map means much more than merely identifying the rock formation at any particular place. You will find it helpful to refer to both a larger scale map (i.e. one inch to the mile) and also a smaller scale (i.e. one inch to ten miles or one inch to twenty-five miles) while you are reading this chapter.

In the key at the side of the map you will see that each Formation or Series is given a distinctive colour and a code symbol. Thus the Cretaceous Formations are coloured in different greens and are indicated by the letter "h," with a number after it to show the actual Formation, such as h^1 for the Weald Clay and h^5 for the Chalk.

You can always find out which are the oldest beds by looking at the key where the most recent beds will be indicated at the top and the oldest at the bottom of the column of colours.

Using a map you can find out at what angle the rock strata are tilted, and this angle is called the ANGLE OF DIP. If you have a one-inch-to-one-mile map (normally known as a "one-inch" map), you will see little arrows, DIP ARROWS, in some (though by no means all) of the places where it has been measured. The arrow points in the downhill direction, and the angle in degrees from the horizontal, is given as a small number beside it.

With a smaller scale map however the dip arrows are omitted, and we have to depend on the sequence of beds and the width of their outcrops as shown on a map, if we wish to determine the tilt of the strata.

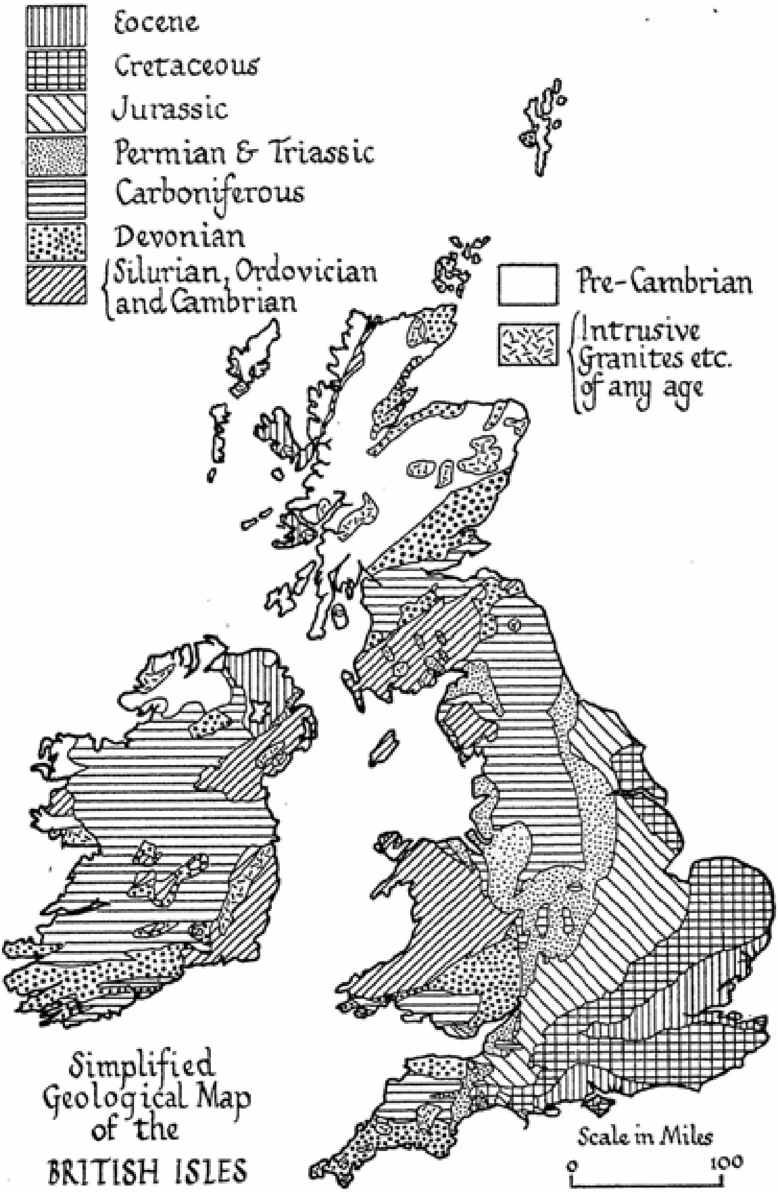

Eocene
Cretaceous
Jurassic
Permian & Triassic
Carboniferous
Devonian
Silurian, Ordovician and Cambrian
Pre-Cambrian
Intrusive Granites etc. of any age
Simplified Geological Map of the BRITISH ISLES
Scale in Miles
0
100

FIG. 23.

Provided that a given bed is the same thickness in different places, the steeper its angle of dip the narrower will be its outcrop. This is shown in Fig. 24 for an outcrop of the chalk in Surrey.

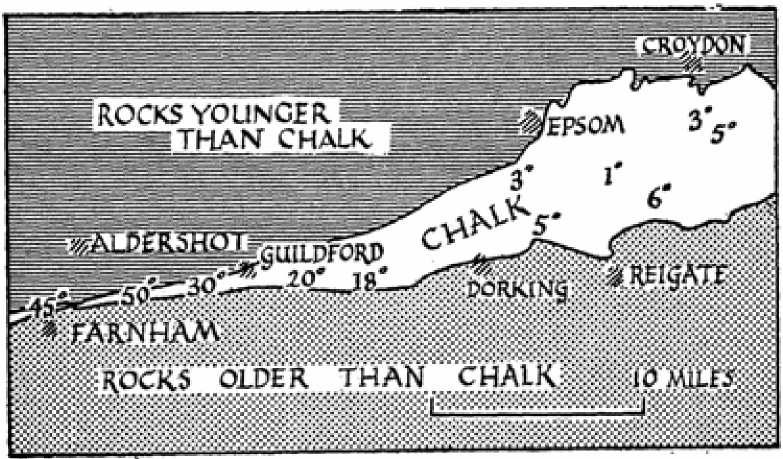


FIG. 24.

Map of the North Downs in Surrey showing how the width of the chalk outcrop narrows towards the west where the dip is greatest, but widens to the east as the dip lessens. The dip arrows are omitted as the beds dip north in all the localities marked.

As a general rule when you have parallel outcrops of different Formations, the beds dip at right angles to the outcrop and in the direction of the more recent strata.

Remember though, that variations in the actual rock thickness will also influence the width of the mapped outcrop. Thus the very pronounced narrowing of the Jurassic outcrops to the north-west of Hull in Yorkshire, is due to the thinning of the strata themselves in that area.

If narrow outcrops run straight across country ignoring contours we can be sure that the strata are steeply tilted, but a succession of narrow outcrops which twist a good deal, and tend to follow the contours, with rivers flowing along the older Formations. will indicate almost horizontal bedding in fairly hilly country. The newer strata are left on the hill tops, and the older have been exposed in the valley bottoms.

This is well seen in the Cotswolds in Gloucestershire.

A concentric pattern with the oldest beds in the middle, (for example, the Weald of Kent or the S.Wales coalfield) reveals an eroded anticline, but a pattern with the oldest beds on the outside, such as the London Basin, is a syncline.

Faults can be detected in inclined strata because the outcrops are displaced along the line of the fault, newer rocks on the downthrow side being brought into contact with the older rocks on the upthrow side. On the larger scale maps the line

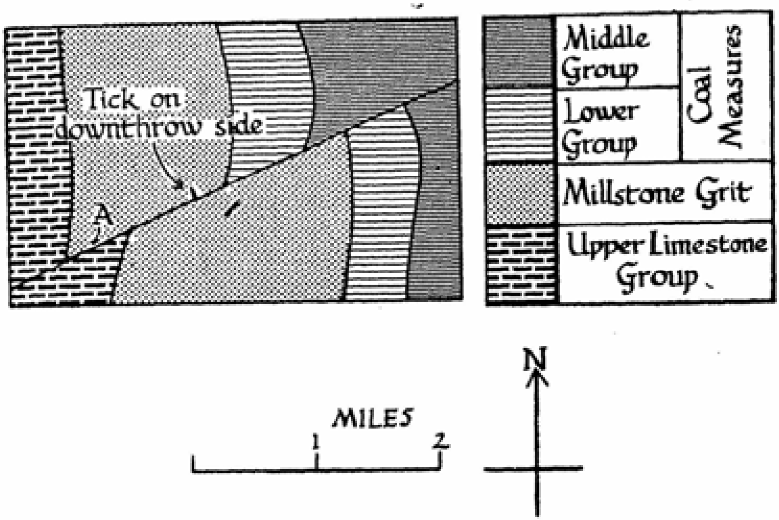


FIG. 25.

Map of fault in Carboniferous strata 9 miles south of Alnwick, Northumberland. Note how the strata are displaced along the line of the fault. At the point such as "A" the younger strata are on the north side, and the older on the south side. Therefore the north is the downthrow side, and this is shown by the position of the tick. In this locality, basalt forced its way up along the fault plane at a time subsequent to the earth movements, forming a dyke called the Causey Dyke.

of the fault is drawn in black or a distinctive colour, with a little mark (see Fig. 25) to indicate the downthrow side.

Only the largest faults such as the Craven Fault in West Yorkshire and the Highland Boundary Fault in Scotland will be shown on the smaller scale maps, as there is insufficient room to mark those of less importance.

A sudden break in the regular sequence of outcrops does not necessarily mean that there is a fault present. In Chapters V and VII you will have read that most sedimentary rocks were laid down as horizontal beds or strata, but in the course of geological time they may become raised far above their original level, both by isostatic movements described in Chapter VIII and also through folding, probably accompanied by faulting.

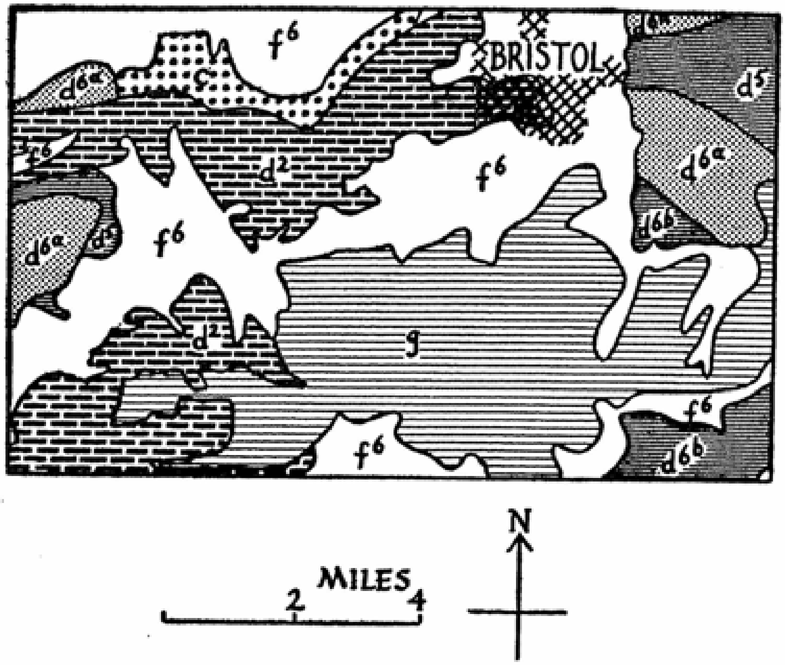


FIG. 26.

d^5. Lower Coal Series.
d^2. Carboniferous Limestone.
c. Devonian.
g. Jurassic.
f^6. Triassic.
d^{6b}. Upper Coal Series
d^{6a} Pennant Series.

Geological Map of the Bristol district, showing the Carboniferous-Triassic Unconformity.

The elevated land is then attacked by the agents of erosion, at first sub-aerial, but later possibly by the sea. This leads to the wearing-down of the folded rocks until the surface in some cases is almost flat. It is on this flattened surface that the new

sediments accumulate in layers. These new sediments will be at quite a different angle from those upon which they rest, and will cut across the earlier ones resting first on one and then on another. A junction of this kind is called an UNCONFORMITY or NON-SEQUENCE. It marks a break in the almost continuous sequence of deposition, and can usually be discovered from a geological map.

As an example, Fig. 26 is based on the geological map of Bristol and the unconformity at the base of the Trias can be recognised because its outcrop rests on Devonian rocks in one place, and on Carboniferous Limestone in another, and so on. A spectacular unconformity exists at the base of the Carboniferous strata in most areas, a result of the gradual spread of the Carboniferous Limestone sea.

Fig. 27 shows a section through Ingleborough in Yorkshire where this unconformity is very clear. Unconformities are very important as they cause sudden and very clear-cut changes in the rock being formed, and they are often used to mark the change from one geological system to another.

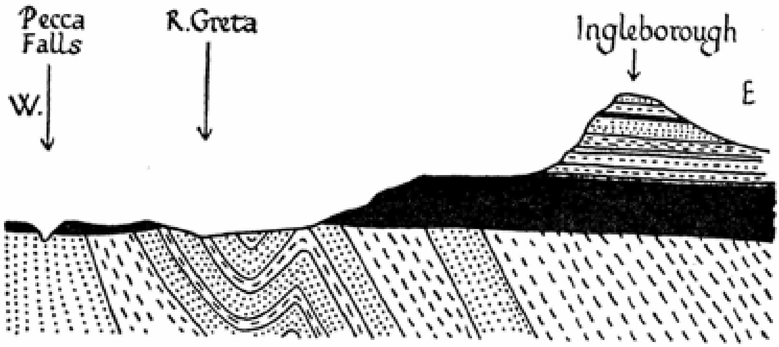


FIG. 27.

Transverse section through Ingleborough in the Yorkshire Pennines. There is a striking unconformity between the folded grits and shales below (possibly Pre-Cambrian) and the horizontal Carboniferous Limestone above, drawn in solid black. Ingleborough is composed of shales, sandstones and limestones of the Yoredale series, whilst the topmost bed is a capping of Millstone Grit. Vertical scale, 2 X horizontal. Length of section, 4 miles.

CHAPTER XIII

CAMBRIAN TO TRIASSIC

CAMBRIAN

THE oldest rocks to contain certain definite fossils in Britain are those of the Cambrian System. These rocks occur in Pembroke, Merioneth, Caernarvon, Shropshire and in a long strip in the N.W. Highlands, as well as in a few other localities. This very disjointed distribution is a result of the rocks being so old that in most places they have been eroded away or buried under later strata.

They are all marine deposits, formed firstly along the shores of a sea which filled a S.W. to N.E. fold in the Pre-Cambrian landscape, and then, as this sea deepened and widened, finer grained deposits accumulated further out from the shores. The greatest thickness is found in Wales, inland from Harlech, and in the Rhinog mountains. Here, there are 11,000 feet of grits and shales, the lower ones being coarser grained and quite unfossiliferous.

Some beds, however are quite rich in fossils, especially in the Upper Cambrian in most of its outcrops. The charac-

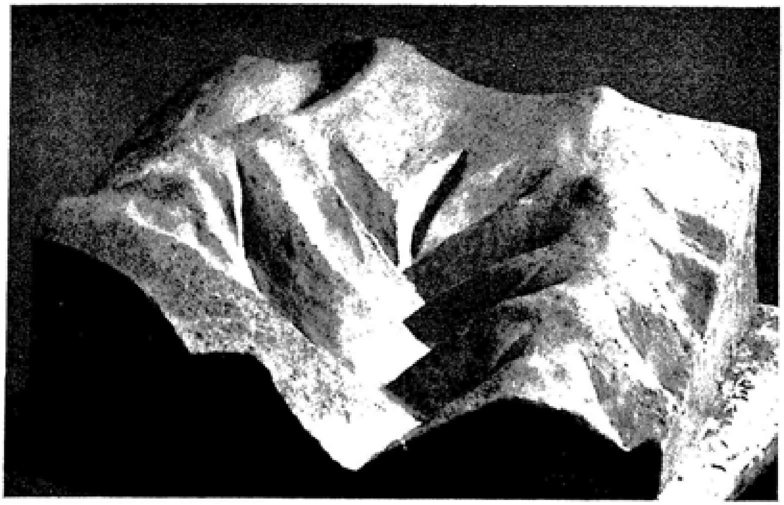
On facing page: MODEL TO DEMONSTRATE GLACIATION IN MOUNTAIN COUNTRY.

Plate 5A.—*Pre-Glacial landscape, valley with interlocking spurs and tributary valleys cutting back into softly rounded hills.*

B.—*The same landscape towards the end of the Pleistocene Ice Age. A glacier occupies the main valley, and is supplied by corrie glaciers at the valley head.*

C.—*The landscape after the retreat of the ice and as we would see it today. The main valley is seen to have been straightened, and the hills to have been deeply cut into by the corrie glaciers. One of the corries contains a tarn, whilst the streams flow in cascades from the hanging valleys into the main one, which has two small lakes amongst the morainic mounds.*

5A



5B

5C

6A West face of Bowfell, Cumberland, showing scree slopes descending from precipitous crags

6B Drying cracks on mudflow of Liassic clay. *Black Ven, Dorset*

teristic fossils are trilobites, of which an astonishing variety have been recorded, whilst in the uppermost beds, the Tremadoc series, the first graptolite *Dictyonema*, appears. The Upper Cambrian Durness Limestone of the N.W. Highlands is famous for its abundance of fossils, mostly partly eroded before fossilization began. These fossils are also interesting because they are quite unlike those creatures which were alive at the same time in Wales and England. Presumably these two faunas could not mingle because they could not swim across the deep Cambrian sea that lay between the different areas.

Ordovician

After the uplift of the Cambrian sea-floor, a certain amount of erosion took place, and subsidence began again. Great quantities of sediments were washed into this sea from the surrounding land areas, whilst at intervals submarine volcanoes poured out pillow-lava under the water—or emerged above sea level to eject clouds of volcanic ash.

The normal fine-grained sediments weather to give fairly gentle hilly country, as, for example, the S. Uplands of Scotland, or the rounded mountains of the northern part of the Lake District. The lava flows are responsible for the great crags and sharp peaked mountains of Cader Idris, Snowdonia and the central Lake District. Towards the end of the Ordovician, volcanic activity died down, and thin limestone bands were formed.

Because rocks were formed under such a variety of conditions they contain correspondingly varied fossil faunas. Thus the shallow water deposits contain a preponderance of brachiopods and gastropods, but the deep water deposits are sometimes rich in graptolites, particularly some called *Didymograptus*, which were shaped like tuning forks.

The main outcrops of Ordovician rocks are in Wales, the Lake District and the south of Scotland. They also occur in small amounts in a few other places, buried deeply under later sediments, in S.E. England.

The five series into which the Ordovician rocks are divided are:

ASHGILLIAN (named after Ashgill, N. Lancs),
CARADOCIAN (named after Caradoc, Salop),
LLANDEILIAN (named after Llandeilo, Carmarthen),
LLANVIRNIAN (named after Llanvirn, Pembroke),
ARENIGIAN (named after Arenig Mountains, Merioneth, W. of Bala).

SILURIAN

Sedimentation continued from the Ordovician Period into the Silurian, in the same marine trough, but under calmer conditions, there being no more eruptions of ash or submarine lavas. The first rocks to be formed were graptolite-bearing mudstones (some of which have been converted into the slates as we find them today), but the water became shallower and shallower as the trough was gradually filled up, and towards the top of the sequence the beds became sandier, together with regular series of limestones. At all periods, however, coarse-grained deposits sometimes of great thickness, were being formed in the shallower marginal waters.

When the water was free enough from mud and warm enough, coral reefs were formed, producing the Ludlow and Wenlock limestones. Each time, however, these animals were killed by fresh influxes of muddy water.

The fossils are typically brachiopods, gastropods and cephalopods (especially straight ones) and graptolites, the latter usually in the deeper water deposits. The Ordovician graptolites were replaced by new types, but even these became extinct at the end of the period.

Beautifully preserved trilobites and corals occur, sometimes in abundance, in the Wenlock limestone.

Silurian rocks occur over much of Wales (extending into Shropshire), in the southern part of the Lake District and the S. Uplands of Scotland, in all of which they follow the Ordovician directly. There are also other minor outcrops, whilst like the Ordovician, Silurian rocks occur at depth in S.E. England.

The System is divided into three series:
LUDLOW series (Ludlow, Salop),
WENLOCK series (Wenlock, Salop),
LLANDOVERY series (Llandovery, Carmarthen).

When the Ludlow and Wenlock series are not fully separable, they are grouped together as the SALOPIAN (Salop = Shropshire).

DEVONIAN

The silting up of the Silurian sea was followed by great earth movements leading to the formation of high mountains, the Caledonides in place of the former sea. The rocks we see today are either coarse screes and sandstones which were carried in vast quantities into fresh water lakes in the northern valleys or a continuation of the Silurian type of sediments including coral limestones in the remnant of the Silurian sea still left in the S. and S.W. of England.

Obviously the faunas of these two major areas are entirely different, the former being notable for curious fishes with armour plating, and for the first land plants, such as *Rhynia* and *Hornea*, whilst the marine fauna was one suited to the littoral conditions, for the main sea area lay further to the south.

During the Devonian Period great volcanic eruptions took place in what is now the midland valley of Scotland, and added considerable thicknesses of lavas and ashes to the coarse sediments forming there.

It is almost impossible to correlate the various outcrops of Devonian rocks, because of their completely different origins, and because of the different basins of deposition, leading to the independent evolution of different animals. The marine rocks of Devon and Cornwall are strictly called Devonian, whilst all the others are grouped together as the OLD RED SANDSTONE (O.R.S.). Both the Devonian and the O.R.S. rocks are divided into Lower, Middle and Upper Series, with further local subdivisions.

The principal outcrops at the present day are:

DEVONIAN:	Devon Cornwall	O.R.S.:	S.E. Wales and Herefordshire, Central valley of Scotland, and N.E. end of Caithness and W. and S. of the Moray Firth.

CARBONIFEROUS

At the end of the Devonian, the sea spread northwards, first filling the S. Wales area of deposition, and then gradually spreading further and further, until only the highest Caledonide peaks stuck out above it.

The first deposits as would be expected, are a basal conglomerate (except in those places where sedimentation was continuous from the Devonian lakes), and great thicknesses of very pure grey limestone, the Carboniferous Limestone, were formed as the water cleared.

As this sea took so long to cover its maximum area, the lower zones were never formed in the more northerly districts, or were replaced temporarily by fresh water deposits.

This clear sea was then invaded by the muddy deposits from the erosion of newly-folded mountains to the north, but with numerous intervals when thin limestones were formed in clear water. These constitute the Yoredale series.

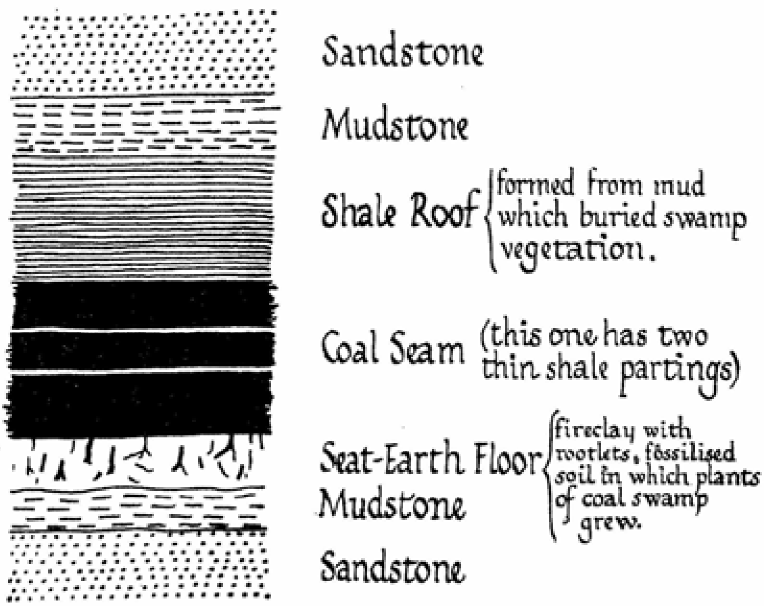


FIG. 28.

Vertical section to show the basic sequence of strata in the Coal Measures. This order of rock types occurs over and over again, indicating a repetition of the same series of events in geological history.

Mountain uplift continued to the north of the Carboniferous sea, and stony rivers laid down thicknesses of coarse deltaic grit deposits, the Millstone Grit (or Culm in Devon). In course of time the sea was filled by these coarse sands, and became low-lying marshy ground covered by luxuriant forests of giant horsetails and clubmosses.

(The descendants of these great trees can be found today in the horsetails by the river, a foot or less in height, and the lowly clubmosses on mountains and heaths.)

The remains of the Carboniferous trees formed the coal seams, lying between beds of sandstone and shale. These are the productive Coal Measures (Fig. 28). From time to time the sea flowed in to a shallow depth over great areas of the low-lying country, leaving thin marine bands.

At the close of the period renewed erosion of the land led to the deposition of coarse grained reddish sandstones on top of the Coal Measures.

Carboniferous rocks outcrop over a very wide area, best seen from the map (Fig. 23), and also occur below more recent rocks in S.E. England, being responsible for the "hidden" coalfield of Kent.

The classification of the Carboniferous is necessarily very complex, and we can do no more here than group the Carboniferous Limestone and the Yoredale Series (in Scotland the Calciferous Sandstone and Carboniferous Limestone Series) together as Lower Carboniferous, and the Millstone Grit, Coal Measures and barren rocks above, as Upper Carboniferous.

Various parallel sub-divisions are based on fossil sequences rather than rock types, and are theoretically much sounder.

Permian and Triassic

Land uplift which began at the end of the Carboniferous continued into the Permian, with a series of large-scale earth movements, which produced the Hercynian or Armorican folds, east to west in the south and in Europe, but north to south in the Pennine region. The remains of the Carboniferous sea evaporated away, leaving first the thin outcrops of Magnesian Limestone of Durham and Yorkshire, and then salt and gypsum beds.

Meanwhile in other areas red sandstones and conglomerates

formed under desert conditions, were washed down from the mountains during great deluges of rain. In most of Britain these desert conditions endured during the Triassic Period too, where the predominant rocks are reddish and yellowish marls and sands, together with deposits of rock salt left when the shallow salty lakes dried up.

The Upper Permian and Lower Triassic sandstones are sometimes grouped together as the New Red Sandstone, as for instance in the Eden valley in Cumberland. The great importance of the Triassic System is that a completely new fauna appeared replacing that of the Carboniferous, which actually died out in the Permian. The animals of this new fauna lived in the sea which has been called Tethys, which covered southern Europe during the Triassic, and did not reach Britain until the Jurassic.

Apart from the northern outcrops mentioned, the Permian also appears in Devonshire, whilst the extensive deposits of the Trias extend from there up to Cheshire and W. Lancashire, and east of the Pennines just into Co. Durham. In addition to the Eden valley, other small outcrops of Permo-Triassic rocks occur in various places in Scotland. The Trias is divided into two series, the Bunter and the Keuper (the third, a series of limestones in between them, does not occur in Britain).

CHAPTER XIV

JURASSIC TO PLIOCENE

Jurassic

FOLLOWING the desert conditions of the terrestial Permian and Triassic Periods resulting in the Hercynian uplift, our part of the land began to subside again, and the Tethys sea spread in from the south bringing with it the new Mesozoic fauna. At the base of the Jurassic System lie the Rhaetic beds, including an extensive bone-bed. These are followed by the clays and cementstones formed in the deepening and widening Liassic sea. This sea extended until it covered most of the country, only the higher Hercynian peaks appearing above the water.

Subsequently conditions became extremely varied and an extraordinary assortment of pure limestones, sands and clays was deposited in different parts, indicating local earth movements, which were sometimes repeated, in several occasions.

The Jurassic rocks of Yorkshire contain many plant remains of the most interesting types. As they are often micaceous flags instead of deep water deposits they must have been formed under deltaic conditions near a land area. The higher beds of the Jurassic are marine limestones, evidently formed near land even in the south of England, whilst the System ends with the appearance in the south, of marshy fresh-water lakes containing a fauna dominated by fresh-water snails.

The Jurassic is an exceedingly rich System as far as rock types are concerned, whilst the rapid alternations of hard and soft strata have a marked effect on the scenery.

The main outcrop lies in a belt running north-east from Dorset to Yorkshire, with smaller outcrops in S. Wales, N.W. Scotland, etc.

Animal and plant life were also most varied in the Jurassic, and some beds are packed with fossils. The most numerous are shells of brachiopods and ammonites. But both on land and sea it was the reptiles that developed the most amazing variety af shapes and sizes (Fig. 29), ranging from the fishlike

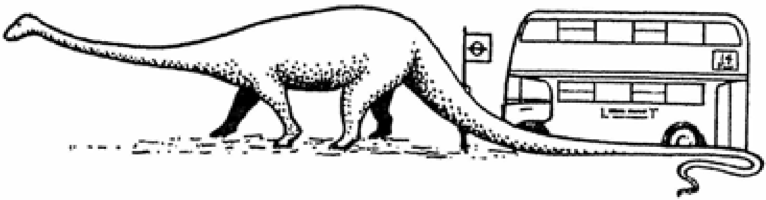


Fig. 29.

Diplodocus—an enormous vegetarian saurian of the Jurassic and Cretaceous Periods, which grew to be as much as 85 feet long. Bones from the tail of a related reptile, Cetiosaurus found near Peterborough, bear swellings suggesting that the animal suffered from rheumatoid arthritis.

marine *Ichthyosaurus* to the enormous swamp-loving *Brontosaurus*. On land smaller active carnivorous reptiles (Fig. 30) ran about making meals of their less wary contemporaries. Particularly interesting were the *pterodactyls*, a group of flying reptiles, some in America with a wing span of as much as 25 feet. An allusive reference has been made to these creatures

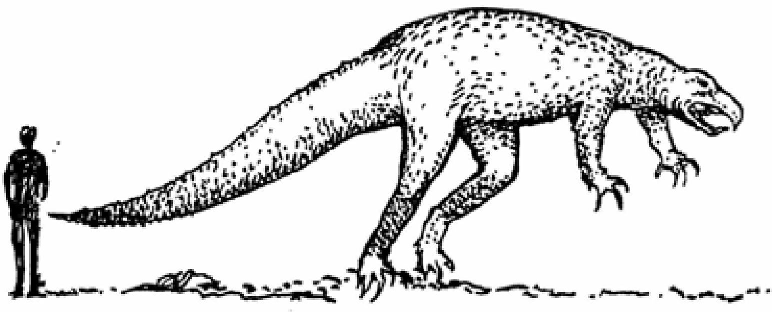


Fig. 30.

Megalosaurus—a flesh-eating saurian of the Jurassic. This reptile ran on its specially strong hind legs, using its smaller front ones for balancing and for holding its prey. Its size can be judged from the silhouette of a man (though it lived some 150 million years before Man's appearance on the earth).

by the Royal Aircraft Establishment at Farnborough, who have recently adopted a new design for their tie, dark blue decorated with golden crowns and silver pterodactyls, these being derived from the crest of their recently granted armorial bearings.

Cretaceous

Sedimentation continued in the south of England directly from the end of the Jurassic. This fresh-water area was gradually covered by a series of deltaic sands and silts which now form the Wealden beds.

Meanwhile in Lincolnshire and Yorkshire the sea once more entered the remains of the Jurassic basin from the east, laying down predominantly marine deposits containing new Cretaceous fauna, very different from the relict Jurassic fauna still persisting in the Wealden area.

Further subsidence enabled the Cretaceous sea to spread over the southern half of England, as the successive sands and clays of the Lower Greensand, Gault Clay and Upper Greensand prepared the way for the great subsidence in which the Upper Cretaceous sea covered the whole of Britain, only the highest mountains emerging as islands. In this sea, probably not very deep, but undoubtedly calm and free from waterborne sediment, the white Chalk was deposited.

The most important Cretaceous fossils belong to the same groups as those of the Jurassic, but there are certain differences between them. Thus, the ammonites uncurl instead of being spiral, and in Britain there is little evidence of terrestial life.

Nevertheless it seems that it was during this Period that the flowering plants evolved from their fern-like ancestors. The main Cretaceous outcrop is to the south and east of the Jurassic belt, with a few small outlying areas such as those of the Upper Cretaceous in Devon, N. Ireland, and N.W. Scotland.

Eocene, Oligocene, Miocene and Pliocene (Tertiary Period)

After the deposition of the chalk at the bottom of the Upper Cretaceous sea, uplift of the sea floor occurred in Britain, together with some gentle folding and erosion. This was fol-

lowed by subsidence in the south-east of the country, where the Tertiary deposits accumulated. These are sands and gravels in the main, including the Bagshot beds of Surrey and the London Clay. These beds all show variation laterally from terrestrial or deltaic conditions in the north and west of their outcrops, to normal marine conditions in the east. From time to time the sea swept over the coastal lowlands due to temporary subsidence, only to withdraw again as the land was uplifted.

Meanwhile violent volcanic eruptions took place in N.W. Scotland and in Ireland, producing great sheets of basalt many hundreds of feet thick, together with very complex igneous masses which cooled within the volcanoes underground, and which are now eroded for all to see.

During Tertiary times the climate was warm, perhaps even tropical in Britain. The fauna and flora were quite similar to that with which we are familiar today, the Cretaceous saurians, ammonites and belemnites having become extinct. A very important aspect of life was that mammals, which had been evolving slowly since the Triassic, suddenly increased in abundance, and we can trace the detailed evolution of such animals as the horse through the Tertiary strata from their Eocene ancestor, Hyracotherium (Fig. 31) (formerly known as Eohippus).

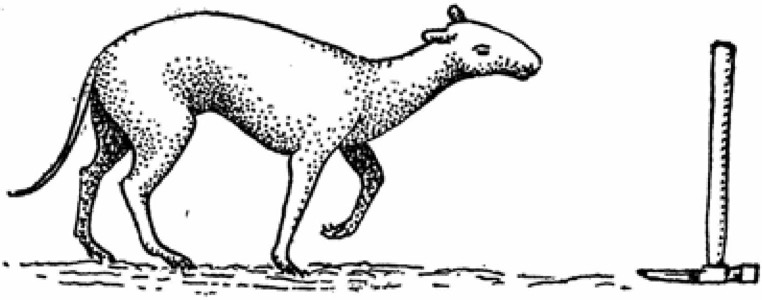


FIG. 31.

Hyracotherium—Eocene ancestor of the modern horse. It was about the size of a fox terrier—as tall as a geological hammer!

The last deposit to be laid down before the onset of the Pleistocene Ice Age, was the Pliocene crag of East Anglia. As

will be explained in the next chapter only the lowest beds, the Coralline Crag, are now regarded as being Pliocene. After this the climate grew colder and the warmth-loving animals were replaced by ones more tolerant of cold.

The Tertiary Period also saw the folding of the Alps and the Himalayan range; the folding of the Weald (an anticline) took place approximately at the same time.

Although we have treated the Tertiary as a single Period, it is as well to list its major sub-divisions because some geologists consider them to rank as separate Periods. Their names are derived from Greek words relating to the frequency with which the deposits are found to contain remains of animal species which are still alive at the present day (i.e. during Recent or Post Glacial times).

PLIOCENE—" more " and " recent "
*MIOCENE—" less " and " recent "
OLIGOCENE—" few " and " recent "
EOCENE—" dawn " and " recent "

Let me remind you that the various geological Periods were very long indeed, the Tertiary Period in itself, lasting for nearly 70,000,000 years. (See the Geological Time Scale on p. 49).

The changes that took place were usually very slow, and geological changes taking place today are part of a period which may well last for many millions of years.

* It may be mentioned here that there were no deposits laid down in Britain during the Miocene Period.

CHAPTER XV

THE PLEISTOCENE ICE AGE

WE have now come to the period in Britain's geological history which has left the greatest impression on the scenery as we see it today . . . the PLEISTOCENE ICE AGE when the greater part of our country was covered from time to time by vast glaciers, and when the climate was so cold that even the Arctic animals were driven south into France and Spain (Britain at that time being joined to the Continent). It was also the time when Man first appeared in Britain.

Contrary to what used to be thought, the Pleistocene Ice Age was very complicated, and consisted of a whole series of separate glaciations (during periods of extreme cold) separated by Interglacial periods (when it was warmer and the ice retreated northwards).

In the Alps there were four main glaciations, each being composite with minor comings and goings of the ice front. In this account we will relate the British glaciations to this well-known Alpine succession.

It is exceedingly likely that climatic conditions affecting so wide an area as the Alps, N. Germany and Scandinavia also affected the British Isles at the same time, but we must remember that there is still a great deal of argument as to certain details of the comparison.

If you look back to Chapter IX you will see that we considered some of the ways in which glaciers erode their valleys, and their numerous deposits, both in the valleys and also over the wider areas of flat country involved when ice sheets spread far afield from their mountain sources.

The partial melting ofthe ice during the interglacials, meant that a vast amount of water was released into the sea, and as

a result the sea level rose to higher levels, only to fall again when a new cold period "locked up" the water in the ice sheets. During the times of high sea level, sea cliffs were eroded which now stand far above the present shore-line, giving us the raised beaches and cliffs, often with caves, to be seen so well in Scotland and Norway, and to a less extent in such places as Portland and the Channel Islands.

You are almost certain to find Pleistocene deposits of some sort marked in the region where you live. If this is south of the Thames, the deposits may be no more than interglacial river terraces, but further north the ground moraine of these old ice sheets covers great areas, as you will see from the Drift editions of the Geological Survey maps.

The earliest Pleistocene deposits are those of the East Anglian Red Crag, a shelly sand formed from a shallow sea. After the Mediterranean warmth of the Coralline Crag, the climate grew steadily colder, allowing the molluscs of the cold northern seas to spread southwards. At the same time the first glaciers spread outwards from the High Alps. The uppermost crag deposits were formed in a distributory of the joint Thames-Rhine river which flowed northwards into the sea beyond what is now the Norfolk coast.

This first cold period was followed by a temporary warming-up, the first Interglacial, when the famous Cromer Forest Bed with its peat full of animal and plant remains was formed.

The second Alpine glaciation resulted from a climatic change for the worse, and at the same time foreign ice came as far as Britain in the form of a great semi-floating ice sheet, moving south-westwards from Scandinavia. This reached into East Anglia, where its ground moraine formed the Norwich Brickearth.

The succeeding warm spell, the second Interglacial period, saw the retreat of much of this Scandinavian ice, and as it melted the sea level rose, and a shallow sea flowed over East Anglia and also into much of N.W. Europe. It seems that this Interglacial period was very long, perhaps about 150,000 years (hence the name "Great Interglacial"), and was characterized by much erosion and redisposition of gravels and sands.

The third Alpine glaciation was contemporary with a great development of "home grown" ice in this country, glaciers

spreading south from Scotland, the Lake District and the Pennines and extending into the Midlands and East Anglia. This was the time of maximum glaciation in most areas, the great southward extent of the glaciers probably being partly due to their being deflected from their easterly courses by the North Sea area still being full of Scandinavian ice.

The ice reached as far as the Cotswolds and the Thames valley, the exact limit can be traced at Finchley in N.W. London, where the original valley of the Thames was blocked by the ice front, and the river had to find a new course to the south through what is now central London.

This widespread glaciation was in its turn, succeeded by a much warmer Interglacial period, once more with flooding of the low-lying country bordering the North Sea. There was a rich flora and fauna, and early Man was active hunting his prey. He was not able to live in the mountain country however, because the higher ground was still icebound.

The fourth and last Alpine glaciation saw a renewal of glacial movement, the north country ice moving southwards across the Irish Sea and down to North Wales, whilst in the east it got just as far as the present north coast of Norfolk, where it stopped. There were probably several advances and recessions of the ice front in the north of England and in Scotland, before the final major retreat and melting took place, but it is certain that the greater part of the southern half of England was not glaciated at all during this last period, and Man lived on through it all, in for example, East Anglia.

The sequence of events of which we know most took place in East Anglia, but it is not so easy to be sure of the conditions in the hilly country of the north and west, as the glaciers there will have lasted for much longer, perhaps in some places enduring completely through an interglacial period. We can tell which way many glaciers moved by looking for ice scratches, seeing which way drumlins point, and by looking for glacial erratics, those pieces of far travelled rock carried by moving ice from distant sources.

The map (Fig. 32) shows the approximate maximum extent of the ice in Britain during the penultimate glaciation.

Geologically it is only a very short time since the final retreat of the ice from this country, and of course there is still

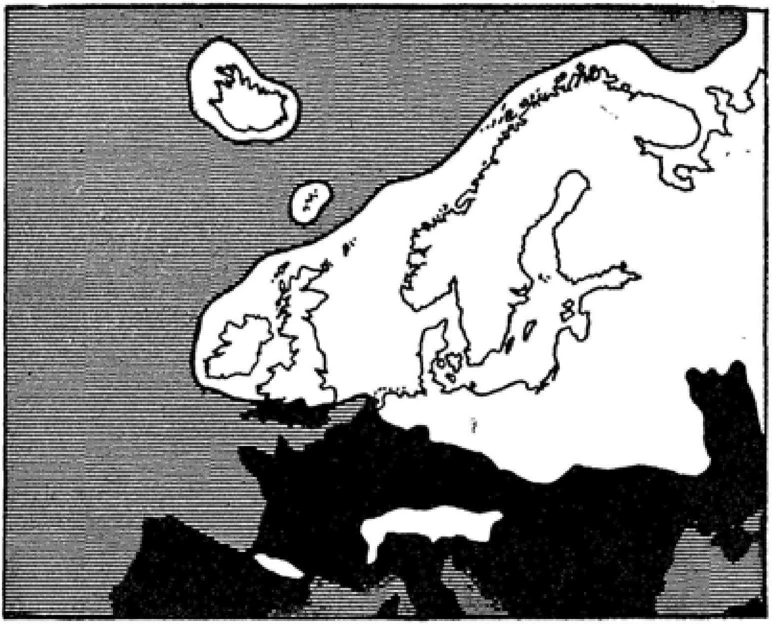


Fig. 32.

Map of Western Europe to show the maximum extent of the ice sheeets (white) during the Pleistocene glaciation. This map does not show the ice limits at any one time, but rather those areas that were covered by ice at any time during the Pleistocene Period.

permanent ice on the high mountains of central and northern Europe. You can see that it is quite likely that another glaciation may still take place in the future, and that we may now be living in a new interglacial period. As a famous geologist pointed out, should another ice age occur, then many of our cities will be overwhelmed by ice sheets, and whole countries will have to be abandoned, but if all the ice caps actually melt away, then so much water will be added to the seas that vast areas of densely inhabited country (including London) will be submerged!

This devastation, in ice or water, concerns only the remote future about which you and I are free to make our own forecast with impunity.

CHAPTER XVI

MAN IN ICE AGE AND PRE-ICE AGE TIMES

AS will become clear in this and the following chapter, MAN has been in existence on the earth's surface for relatively only a very short time.

As you will recall from Chapter XI, it used to be thought that Man descended from apes, that is to say. from chimpanzees and gorillas, but in actual fact this idea is quite im-

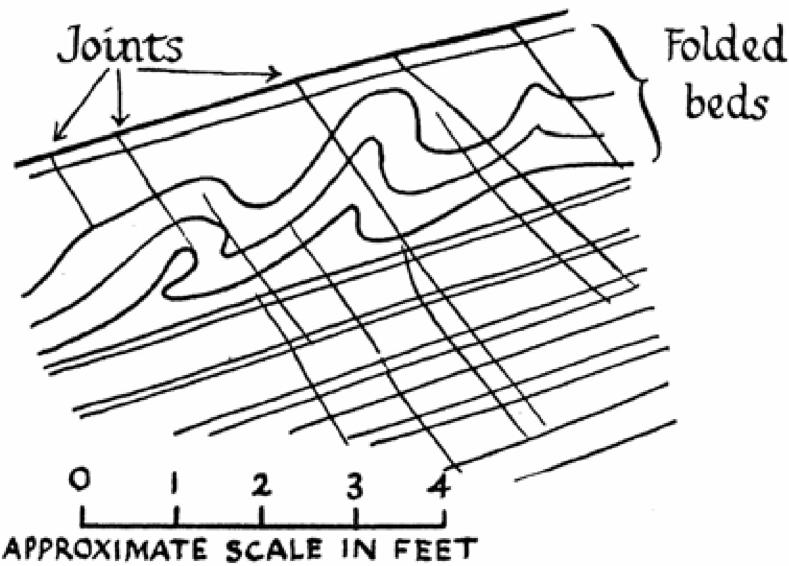
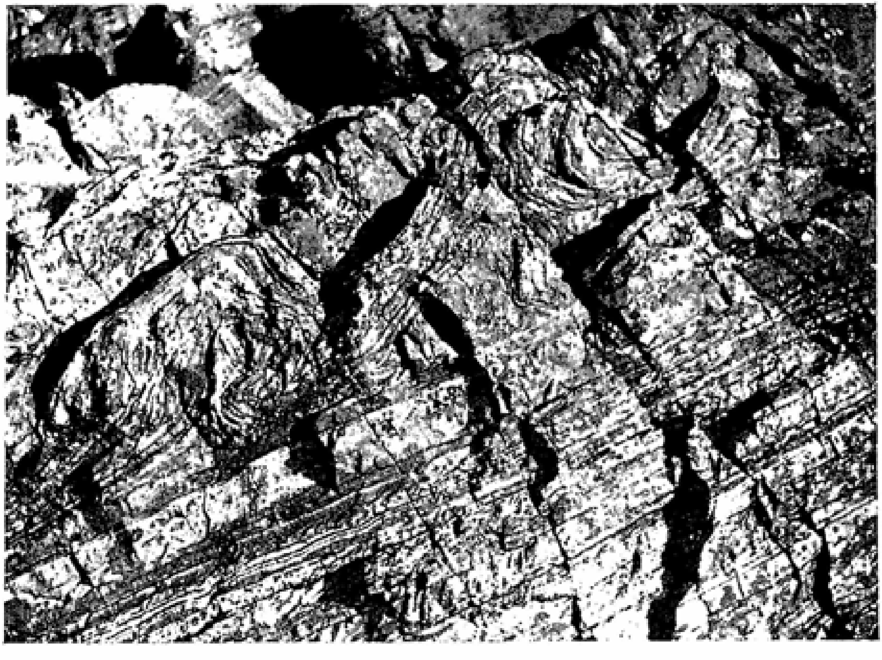


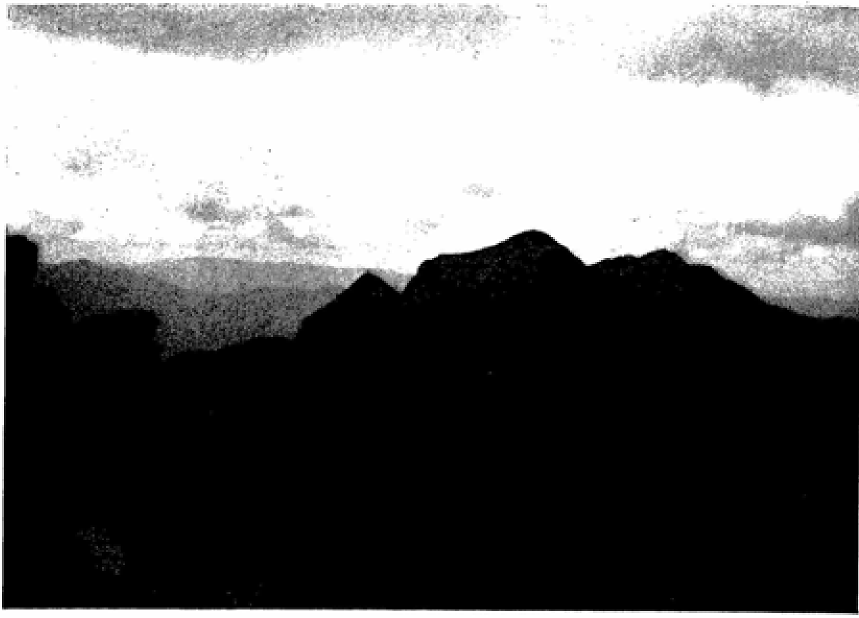
FIG. 37.

Diagram to explain rock formation in photograph (B) Plate. No. 7.B. The folded beds lie sandwiched between others which are not folded. The folding probably took place before the sediment had consolidated, this particular bed sliding as a soft sludge down a submarine slope.

7A A promontory composed of a coarsely crystalline gabbro. *Carrick Luz, Lizard Peninsula, Cornwall*



7B Inclined bedded tuffs on Bowfell, Cumberland. *(See explanatory diagram opposite)*



8A The Torridon Mountains, Wester Ross, Scotland, formed from horizontally bedded Pre-Cambrian sandstones

8B A valley greatly deepened by glacial action and now flooded by the sea

Aurlandsfjord, Sogn og Fjordane, Norway

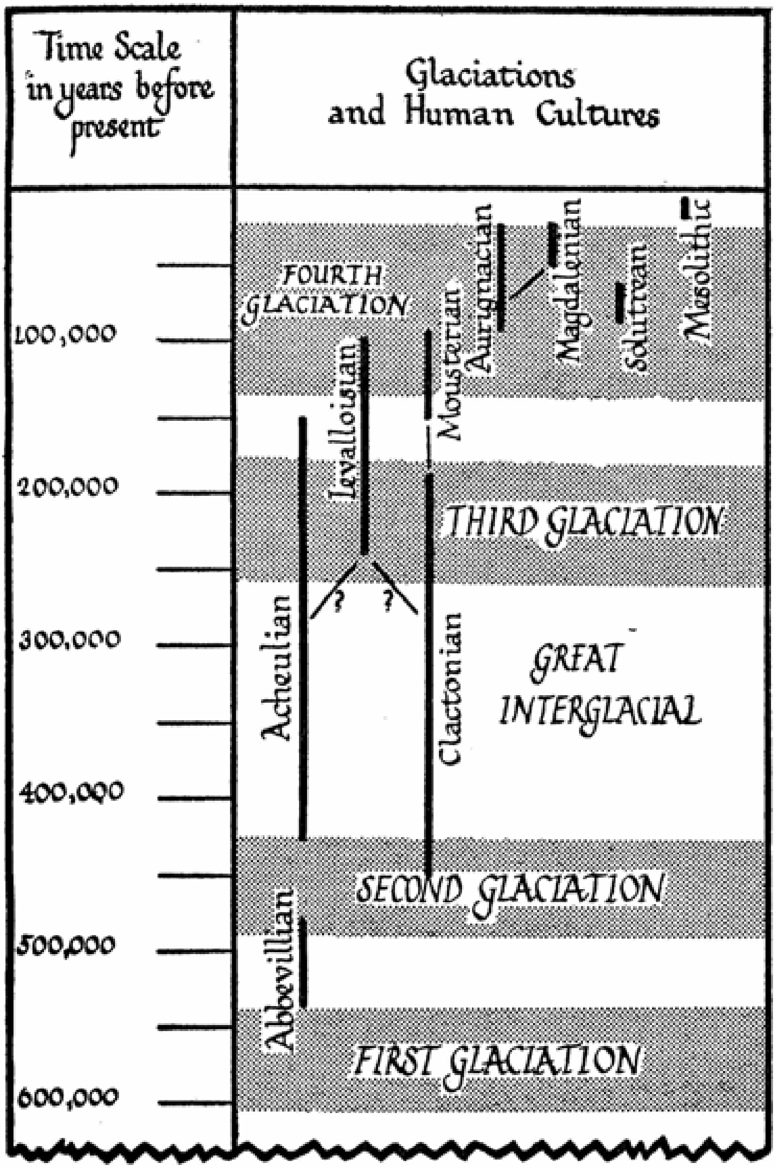


FIG. 33.

Table showing the succession of Palaeolithic Cultures in Western Europe, and their relation to the four glacial phases.

possible, in spite of newspaper references to apes (or still worse, monkeys) as being Man's original ancestors. Anthropologists today consider it much more likely that *both apes and man originated together from a group of related ape-like animals in the Miocene Period*, remains of which have been found in Kenya, and they combined ape-characters with Man-characters in a curious way.

In the lower Pleistocene of Bechuanaland a recently-discovered group of fossils, belonging to the genus AUSTRALOPITHECUS seem to have evolved from Miocene "apes," but although they did not seem to have used stone tools, they held themselves erect and were more like present day Man than apes.

Also of lower Pleistocene are the eastern fossils, commonly called JAVA MAN and PEKING MAN. These creatures also walked erect, and had very thick brow ridges and were chinless. They made crude stone tools and perhaps knew how to use fire.

As soon as we come to Man-made tools, we have a most useful system of identification for the fossil remains, and also of dating the gravel and tufa deposits where they occur. For long periods a particular group of early Men and their descendants would make their stone tools in particular and characteristic ways. They might, for instance, always use long flakes of stone, from which they would knock off smaller flakes to give a sharp cutting edge, in such a way that we can always recognise them. These tools would all belong to the same CULTURE of tool-making, and be named after the place where the culture was first described (in the same way that we name rock formations after their type localities). There is for instance the AURIGNACIAN culture, named after the particular local industry of flint tool-making carried on at Aurignac, Haute Garonne, in the south of France. Industries producing similar types of stone implements in other parts of the country would be grouped together in the same culture.

In Fig. 33 the main cultures for Britain and Western Europe are shown by their names against lines showing the approximate times when they existed. These cultures all belong to the Palæolithic stage of human development, commonly called the Old Stone Age. As you can see, these Stone Age Men

lived throughout the middle and latter parts of the Ice Age. They were hunters of the large herbivorous animals that fed on the grassy vegetation growing in the areas just south of the ice sheets. As much of Britain was covered by ice during the two middle glaciations, Man could only live here during the warmer interglacial periods, being driven even from his mountain caves by the ice. It must be remembered that Britain was joined to the Continent by a " land bridge " during much of these early days, and Man could retreat to warmer parts in southern Europe during the worst periods of glaciation, following the animals on which he lived who also moved south as the cold increased, but he was able to last out in the south and east of England during the final and less severe glaciation.

From early times (i.e. the Great Interglacial) creatures almost indistinguishable from present day Man have been in continuous existence, making for example, ACHEULIAN tools, as did SWANSCOMBE MAN (named after Swanscombe in Kent where his fossil remains were found), and later, those responsible for the AURIGNACIAN and MAGDALENIAN cultures. These latter people produced the marvellously delineated cave paintings in the Pyrenees and S.W. France during the last glaciation. From them the Middle Stone Age (Mesolithic) and New Stone Age (Neolithic) people were developed, but they all, including Swanscombe Man, belonged to the same species to which you and I also belong, namely *Homo sapiens*.

During the latter part of the Ice Age, a group evolved which, as time progressed, became more and more like apes in appearance. They are called NEANDERTHAL MAN, and are put in a separate species, *Homo neanderthalensis*. They are known to have made the MOUSTERIAN type of implement. They lived in Europe, Africa, and Asia, but in spite of this wide spread, they became extinct before the final glaciation.

We may mention here the peculiar case of PILTDOWN MAN, who has caused anthropologists so much more trouble than he was worth. The fossil remains found in gravel at Piltdown in Sussex seemed to be those of an early man, judging by the pieces of brain case, but with a jaw almost exactly like an ape, in fact, apparently, a missing link between ape and Man.

The problem was solved by recent chemical analysis, which

proved that the jawbone was really one from a modern ape stained to look like the genuine skull fragments, and that Piltdown Man was a deliberate hoax!

The missing link between ape and man is not to be found in the Pleistocene, but in their common ancestors, the "apes" of the Miocene.

CHAPTER XVII

POST-ICE AGE

THE period between the last glaciation and the present day is of the utmost importance, because it has seen the evolution of so much of our scenery, of the present flora and fauna of these islands and also, of course, it has seen the evolution of Man from the Palæolithic stock of the late Pleistocene to Man is he is today.

There are several ways of working out relative ages and dates for this Post-glacial time, the one most commonly used depends on the succession of increasingly complex human cultures, from those of the Palæolithic, through the Mesolithic and Neolithic, up to the Bronze and Iron Ages, which leads into historical times. Really though, these are only relative stages, and they vary in actual time from place to place. As an extreme example, certain tribes in New Guinea are (or at least were, until discovered recently), still no further advanced than the Palæolithic stage.

A much better time sequence is obtained from the vegetation changes which result from the changing climatic conditions. We can learn a great deal about these conditions by looking in old peat deposits for the remains of the pollen grains of plants which grew nearby and which even now are still identifiable. As a result of this, and by looking for leaves, stems, etc., we can discover whether they were widespread forests or not, and also what kind of trees used to grow there. We can also discover what the smaller plants were like. In these same peat beds we find bones of the contemporary animals, and if we are very lucky, the remains of early Man.

Using these and many other lines of evidence, we can piece together this post-glacial history as a whole, and relate it very cautiously (because of unavoidable errors in estimating the

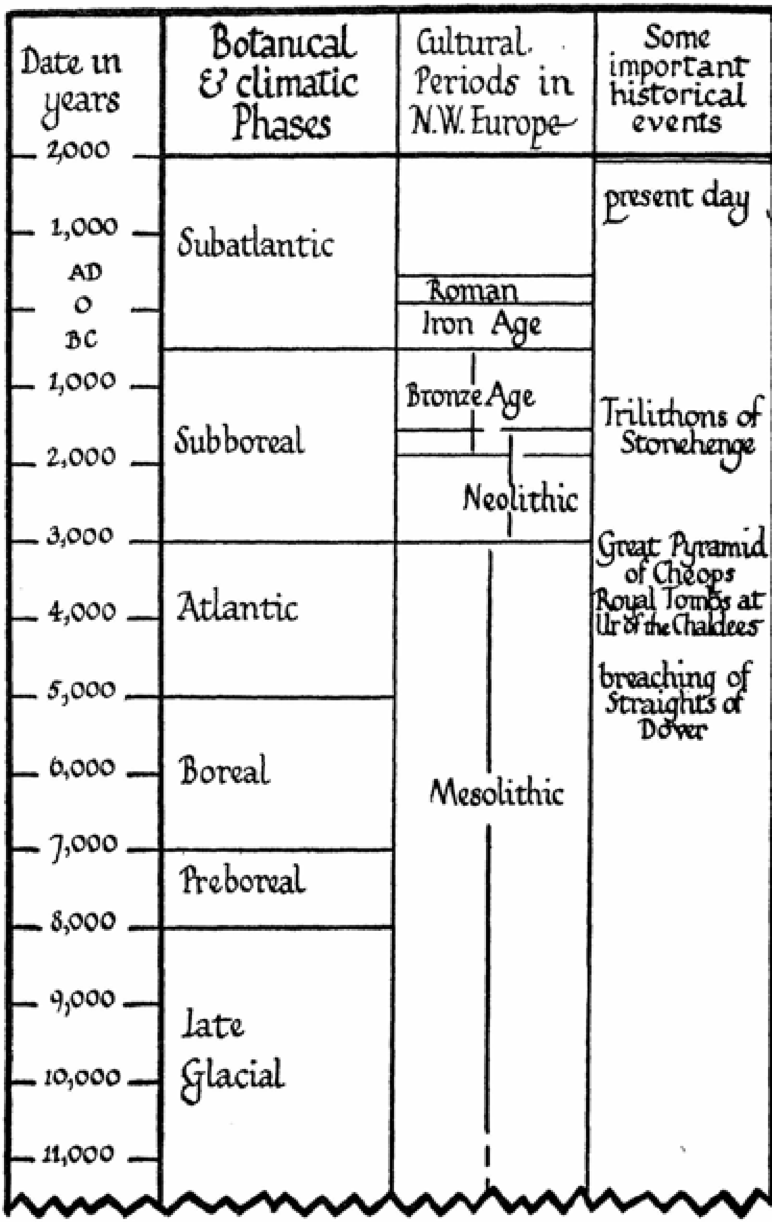


FIG. 34.

Table to show the subdivisions of the Post-Glacial period in Britain.

times involved), to an actual time-scale in years B.C. The main post-glacial time periods, based on botanical evidence, are given in the table in Fig. 34. I have also included the equivalent stages in the development of human culture in Britain, together with an approximate time-scale.

The northward retreat of the ice began after the last glaciation about 20,000 years ago. This retreat was irregular, leaving a belt of bared gravel ready to be colonised by vegetation.

Plants were able to spread into this moraine covered land, often springing so rapidly as to grow on the stony soil overlying masses of buried ice which had not yet melted, as one can see in many northern districts at the present day. The first general vegetation type to become established was of a Tundra type. Curiously enough many of what we now regard as garden weeds grew on the bare stony ground during this period, amongst them we have evidence of dandelion, buttercup and silverweed.

Very large herbivorous animals grazed the turf, deer and horses being particularly common, whilst the giant elk grew to such a size as to have developed antlers with a span of as much as nine feet.

This tundra period is called the Late Glacial. You will see from Fig. 34 that it ended approximately 8,000 B.C., but the date when it started will vary according to the time when the ice melted away from the region in question.

The very cold Late Glacial was followed by a definite warming with an increase in woodland during the Pre-Boreal phase. These first woods were mostly pine, but they were replaced by birch in the Boreal period which followed.

The large herbivores became more and more scarce as their grazing land became overgrown by trees, and of course they were also being continually hunted and eaten by Palæolithic Man.

Mesolithic Man evolved from Palæolithic Man in the Late Glacial. He too was a hunter, and used similar weapons, but more perfectly finished, and in addition, made bone spears and harpoons with sharp barbs. It would seem that he disliked forests or that he was particularly fond of fish and molluscs, as he lived by the watercourses fringing the densely wooded land. He built wooden houses on piles in the shallow water

at the edges of lakes, and a village of this type has been discovered near Seamer in the Vale of Pickering in Yorkshire. By a stroke of fortune for the excavators, over 60 barbed fish spears were found there.

Much of the North Sea was dry land during the Boreal, and Mesolithic Man hunted over what is now the Dogger Bank. Fig. 35 shows the outline of the coast at the beginning of the Boreal, making a wide land bridge between Britain and the Continent. The North Sea area, including S.E. England, began to sink in the Boreal, and the sea flowed over

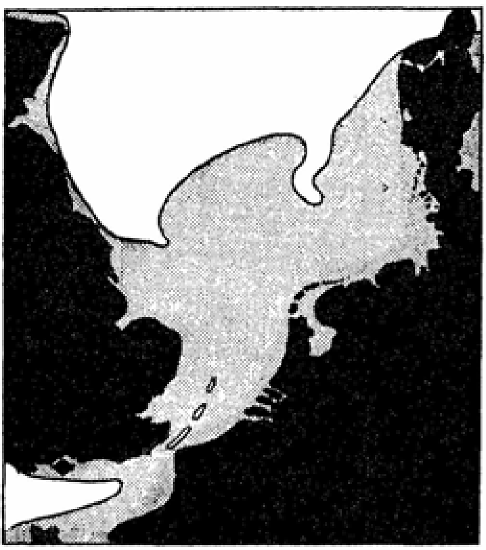


FIG. 35. The southern part of the North Sea during the Early Boreal, about 7,000 B.C. Present day land in black. Land in Boreal but now submerged by the sea, stippled. This stippled area shows the "land-bridge" which connected Britain to the Continent.

the low-lying country. By about 5,000 B.C. it entered the shallow valley previously cut in the chalk ridge between Dover and Calais, and in the course of time this valley sank until it became permanently occupied by the Straits of Dover.

This severance of Britain from the Continent was a major event in the country's history, as it prevented the easy immigration of plants and animals (including Man) from the Continental mainland.

The formation of the English Channel was approximately coincident with the start of the Atlantic phase, when the

Boreal birch and pine-woods gave way to a dense forest of oak and alder, which covered most of the country. In addition, the weather was warm, probably warmer than it is at present.

While Mesolithic Man hunted in Britain, his contemporaries in the Middle East were developing farming and the cultivation of crops. Grains of cultivated corn have been found dating back to 6,000 B.C. in Palestine. From these early farmers there grew the great civilisation of Egypt and Sumaria, and between 4,000 and 3,500 B.C. the Great Pyramid of Cheops by the Nile, and the incredible burial chambers at Ur beside the Euphrates, were being built for their rulers.

From the Middle East the new farming tradition spread outwards and first appeared in Britain with the arrival of Neolithic Man from the Continent in about 3,000 B.C. These people must have crossed the, at that time, shallow English Channel, perhaps by boat with their domesticated cattle, or by wading across at periods of low Spring tides. The country was then covered by the dense deciduous forests of the Atlantic period, and the Neolithic farmers felled the trees over extensive areas, starting the decline in our woods that has continued without pause to the present day. During this period the burial mounds or Long Barrows, were built on our Southern Downs, and the megalithic tombs in the West country.

During the middle of the Sub-Boreal yet another invasion took place, this time by people from Eastern Europe who had learnt the use of Bronze (the alloy of copper and tin). Bronze was the first metal to be used on a large scale for weapons and implements, as pure copper was found to be too soft for many purposes. Bronze was first produced in the Middle East at least a thousand years earlier than in Britain, and the invaders quickly discovered deposits of copper and tin in the metamorphosed rocks in Cornwall as well as valuable gold in Ireland.

The Late Bronze Age saw the arrival of the Celts, whilst in the following years other invasions took place during the Iron Age and later. Iron was used in Asia Minor for tools and weapons some 800 years before its use spread to Britain. Our earliest forefathers appear to have been rather backward people.

In the Iron Age and the years that follow we come to his-

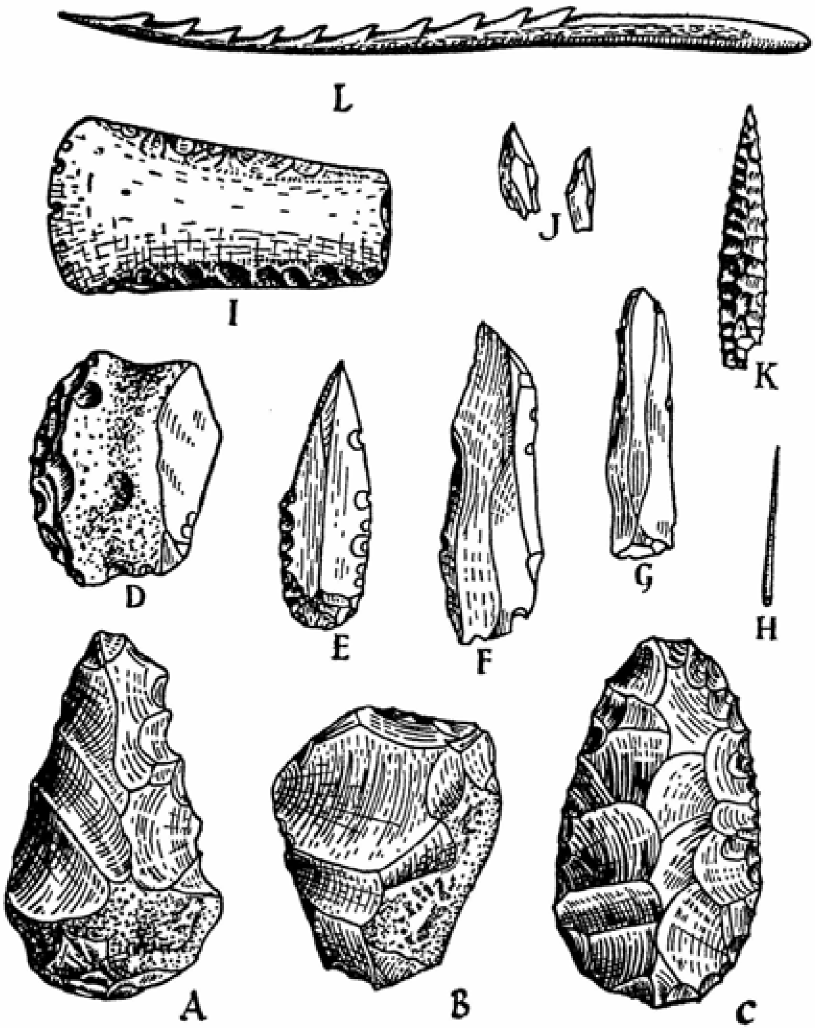


FIG. 36.
VARIOUS FLINT IMPLEMENTS.
(Approximately one-third natural size)

A. Abbevillian hand-axe.
B. Clactonian scraper.
C. Acheulian hand-axe.
D. Mousterian side-scraper.
E. Aurignacian blade tool.
F. Levalloisian flake tool.
G. Magdalenian blade tool.
H. Magdalenian bone needle.
I. Neolithic flaked and polished axe head.
J. Mesolithic microliths.
K. Pressure-flaked Solutrean arrowhead.
L. Mesolithic bone harpoon.

toric times and can leave our history of the Evolution of Man. It is salutory to look at the diagrams on pp. 113 and 118, and to ponder over the vastness of the time-scales to realise just how short a time Man has existed on earth in relation to the immensities of geological time.

Fig. 36 shows some typical flint implements.

CHAPTER XVIII

METAMORPHIC AND PRE-CAMBRIAN ROCKS

I HAVE deliberately left until the last a brief explanation of the oldest and most difficult rocks of all for the beginner to understand, those we call Pre-Cambrian and those that have been metamorphosed. Underneath the cover of fossiliferous strata are great (and unknown) thicknesses of rocks formed at many different times early in geological history. These are generally grouped as PRE-CAMBRIAN or ARCHAEAN rocks, and apart from a very few and sometimes rather dubious specimens, these vast rock masses are quite unfossiliferous. They form cores to the continental blocks, and are exposed over large areas where all the later sediments have been removed by erosion. This has happened for example, in much of Canada and Finland.

When originally formed, these rocks were the normal granitic and basaltic igneous rocks, together with the sandstones and clays derived from them by weathering, exactly as is happening *now*. However the Archaean rocks were formed an immensely long time ago, for the Pre-Cambrian ages lasted for about five times as long as the period between the Cambrian and the present day.

During this time the early rocks have been eroded, folded and altered by heat and pressure to such a profound extent that they are often quite unrecognisable, and have in fact been transformed into new rock types. These altered rocks are said to be METAMORPHIC. The main changes result from intense pressures and temperatures acting on them during earth movements at considerable depths within the earth's crust. (Fig. 38 shows a metamorphosed belemnite.)

Similar changes have happened in much more recent rocks as well, especially near large intrusions of granite, or on a

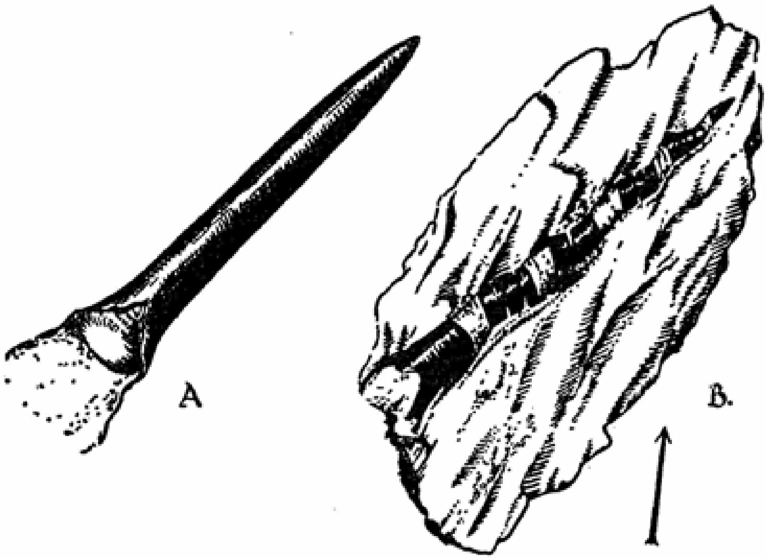


FIG. 38.

The effect of pressure on a fossil. (A) shows a typical Jurassic belemnite. (B) shows a similar specimen, but broken and distorted by intense pressure in the direction of the arrow. The spaces between the belemnite fragments have been filled with calcite, whilst the shale has been converted almost into a schist.

(B) is from La Grave, Hautes Alpes, France.

smaller scale close to dykes or lava flows, producing perfectly genuine metamorphic rocks. The greatest masses of such rocks are however, Pre-Cambrian in age. Actually the most recently formed Pre-Cambrian formations are not crystalline metamorphic rocks, but are hard coarse-grained sandstones such as the Torridon Sandstone of the N.W. Highlands. In that area and in Anglesey these Pre-Cambrian sediments rest unconformably on the crystalline metamorphic group.

Before commenting on the different Pre-Cambrian outcrops, it would be well to describe the metamorphic rock types, together with the original sediments from which they are formed.

1. PURE LIMESTONES change easily when intensely heated, although they do not lose CO_2 (as when inside a limekiln),

because they are sealed deep within the overlying rocks. The calcite recrystallizes to produce a true MARBLE.*

2. IMPURE LIMESTONES with clay minerals present in quantity produce instead when heated a particularly tough lime-silicate rock called HORNFELS. Most of the precious gem-stones are found in weathered exposures of metamorphosed calcareous rocks.

3. CLAY STONES and other fine-grained sediments show very varied results according to the degree of metamorphism. Simple pressure produces first a shale, and then, if much more intense, a slate. Slates split into thin sheets because of the "slaty cleavage" that develops in these rocks at right angles to the direction of pressure, and thus possibly cutting completely across the bedding planes.

The elongated clay minerals arrange themselves at right angles to the direction of pressure, so do the minute flakes of the minerals MICA and CHLORITE which develop in these conditions. The cleavage then appears between and parallel to these flattened plate-like crystals.

The greenish Ordovician slates of the Lake District are formed from compressed volcanic ashes. Similar are the purple Cambrian slates from Llanberis in N. Wales. More intense metamorphism enables these shiny mica and chlorite crystals to grow large enough to form more or less continuous layers, and the smooth glistening rock that results is called a PHYLLITE.

When the heat has been very intense too, recrystallization of the rock will begin in quantity, and the claystone ends up as a MICA SCHIST. This has large, easily visible crystals of mica as the dominant mineral, and probably also prominent red garnets. The rock as a whole will still cleave because of the parallel arrangement of the mica flakes.

4. Most IGNEOUS ROCKS can also be changed by intense heat and pressure. This may seem surprising, because you know that they have been formed from molten magma. When they are being metamorphosed however, the rock does not

* Many limestones are sold as "Marble," provided that they are hard enough to polish, and reveal an attractive pattern or colour, such are the Jurassic "Purbeck Marble" and the Rhaetic "Ruin Marble." Neither is a true marble.

have a chance to flow like liquid magma, instead all the chemical changes and recrystallizing happen in more or less the same place, and at the same time.

The great pressures involved often produce some lateral movement, and we find such rocks transformed into coarse-grained banded crystalline rocks called GNEISSES. In the light-coloured bands the most important mineral is feldspar, and the associated minerals suggest the composition of typical granite; but the dark and light banding of the rock as a whole show that it is metamorphic gneiss and not a granite. Gneiss and true granite can sometimes be closely intermingled, and then it becomes very difficult to tell where one ends and the other begins.

5. The SILICEOUS SEDIMENTS are the rocks that are the least affected, especially pure sandstones. These simply recrystallize to produce an extremely hard metamorphic quartzite, in which the quartz grains are fused together. You will remember that sandstones can also be converted to quartzite by the cementing together of the grains by secondary silica deposited from percolating solutions.

Feldspathic sandstones (arkoses) and sandy sediments with clay minerals as well may produce types of gneiss, because of the greater variety of minerals present.

The Pre-Cambrian SERPENTINE outcrop in the Lizard peninsula, Cornwall, is a metamorphosed rock which is composed of such dark ferromagnesian minerals as enstatite and olivine. In the course of time much of the olivine has been converted to the mineral serpentine, and also in places where sliding movements have occurred, schists with talc and asbestos have developed.

When we consider the relative ages of these early rocks, we meet with almost insurmountable difficulties, even though the rocks underlie more recent strata in all parts of the country.

It is not possible to correlate the Pre-Cambrian rocks of one isolated outcrop with those of another, because their sequence is concealed and confused by profound earth movements and metamorphism.

Even in Scotland where these rocks are at the surface over many hundreds of square miles of mountain country,

the order in which they were formed is still largely unknown.

The main Pre-Cambrian outcrops in Britain are those of the Scottish Highlands. Most of the country north and west of the Highland Boundary Fault (which runs S.W. from Aberdeen to the Clyde) is composed of a great variety of Pre-Cambrian schists and other metamorphic rocks. A glance at a geological map will show the complexity of this area. To the west of the Moine Thrust plane, emerging from beneath the Torridon sandstone, we can see the oldest rocks in Britain, the Lewisian Gneisses.

An important, but much smaller group of outcrops are those of Shropshire, where the Longmynd is formed from almost vertical sedimentary grits and slates, and the steep hills of Caer Caradoc and the Wrekin from volcanic lavas and ashes.

Other outcrops of the Pre-Cambrian occur in Anglesey, Pembroke, Charnwood Forest in Leicestershire, the Malvern Hills in Worcestershire, and the Lizard district of Cornwall.

In this book I have tried to give you a summary of the history of our country's rocks, from the earliest times to the present day, stressing the ever-changing nature of scenery and land form. I hope that you will be interested enough to pursue the subject further, using maps and more advanced books to help you in what should always be essentially a field study, and I can assure you that the further you go with this study, the more rewarding you will find it to be.

Suggestions for Further Reading

A. Holmes: *Principles of Physical Geology,* Nelson, London, 1945.

L. Dudley Stamp: *Britain's Structure and Scenery,* Collins, London, 1947.

A. K. Wells: *Outline of Historical Geology,* Allen and Unwin, London, 1938.

H. H. Read: *Rutley's Elements of Mineralogy,* Murby, London, 1946.

A. Morley Davies: *An Introduction to Palaeontology,* Murby, London, 1947.

H. H. Swinnerton: *Outlines of Palaeontology,* Arnold, London, 1947.

There are also numerous books and booklets on more specialist aspects of Geology published by the British Museum (Natural History), and by H.M. Stationery Office for the Geological Survey.

GLOSSARY

These definitions are necessarily abbreviated and should NOT be regarded as comprehensive.

ACIDIC ROCKS ...	A general term for quartz-containing igneous rocks such as granite.
AGGLOMERATE ...	Breccia composed of fragments of lava shattered by volcanic eruptions.
AMMONITE	An extinct cephalopod with an external, spirally-coiled chambered shell.
AMPHIBOLES	A group of rock-forming silicates.
ANDESITE	A fine grained extrusive igneous rock.
ANTICLINE	An upfolding of strata caused by lateral pressure.
ANTHRACITE	A hard and very pure form of coal.
ARCHAEAN ROCKS ...	Crystalline rocks of the older part of the Pre-Cambrian.
ARKOSE	Sandstone containing grains of chemically fresh feldspar.
ARMORICAN	A period of mountain-building at the end of the Carboniferous and beginning of the Permain. Also called "Hercynian."
ASH BEDS	Accumulations of volcanic ash.
ATLANTIC PHASE ...	A climatic stage in the Postglacial.
AUGITE	A black proxene found in basic igneous rocks.
BASAL CONGLOMERATE	A conglomerate underlying many formations, usually formed from the shore deposits of a spreading sea.
BASALT	A fine grained extrusive igneous rock.
BASIC ROCK	A general term for quartz-free igneous rocks such as basalt.
BELEMNITE	An extinct cephalopod, related to cuttle-fish, with a straight, internal chambered shell.
BERGSCHRUND ...	Prominent crack in ice below steep crags in a corrie.
BIOTITE	A type of mica, forming black crystals.

BLUE LIAS	... ...	The lowest beds, clays and thin limestones of the Jurassic.
BONE BEDS	... ...	Strata largely composed of fossil bones, generally much broken.
BOREAL AGE	... ...	A climatic phase in the Post-glacial.
BOULDER CLAY	...	Glacial clay rich in rock fragments.
BRACHIOPODS	...	"Lampshells," marine bivalved animals with a fleshy stalk coming through a hole in the upper valve.
BRECCIA	... ...	Sedimentary rock composed of large angular fragments.
BRICK EARTH	... ...	Very fine-grained wind-blown deposit, laid down in water during the Pleistocene.
Brontosaurus	...	A huge herbivorous reptile of the Upper Jurassic.
BRONZE AGE	... ...	A phase in the Post-glacial based on Human Cultures.
BROWN COAL	... ...	A substance intermediate in composition between peat and coal.
BROWN EARTH	...	A rich, unleached type of soil characteristically developed in British deciduous woods.
BUNTER	... ...	Lower series of rocks in Triassic.
CAINOZOIC	... ...	The third Era whose rocks contain definite fossils.
CALCAREOUS GRIT	...	Carboniferous sandstone with calcium carbonate as the cement.
CALCITE	... ...	Crystalline calcium carbonate.
CALDERA	... ...	Immense volcanic crater, sometimes miles across.
CAMBRIAN	... ...	The first Period in the Palaeozoic. The System of rocks formed in that Period.
CARBONIFEROUS	...	The fifth Period in the Palaeozoic. The System of rocks formed in that Period.
CARBORUNDUM	...	An artificial corundum made as an abrasive.
CAST	... ...	The solid material filling a mould subsequent to the removal of the object which originally occupied the cavity.
CEPHALOPOD	... ...	A group of marine animals, including the squid and octopus.
CEMENT	... ...	Fine grained substance binding together larger rock fragments.
CEMENT STONE	...	A calcareous mudstone.
CHALK	... ...	Soft white limestone, the principal example being that of the Upper Cretaceous.

CHERT ... ... A flint-like rock found in strata older than the chalk.

CHINA CLAY ... ... See Kaolin.

CHORLITE ... ... A greenish mineral, related chemically to the micas.

CLAY ... ... Sedimentary rock composed of very fine particles.

CLAY-WITH-FLINTS ... Residual deposit resulting from weathering of chalk.

CLINT ... ... Thin vertical walls of limestone separating grykes.

COAL MEASURES ... Coal-bearing strata in Carboniferous rocks.

CONE SHEET ... ... Dykes in the form of inverted, concentric cones.

CONGLOMERATE ... Sedimentary rock composed of rounded rock fragments cemented together.

CONSOLIDATION ... The process of a sediment becoming compacted and hard.

CONTINENTAL DRIFT ... Theory that continents have been gradually drifting apart in the course of geological time.

CORALLINE CRAG ... Pliocene sands in East Anglia.

CORRIE ... ... Semi-circular depression in mountains caused by small glaciers. Also known as CIRQUE or CWM.

CORUNDUM ... ... Aluminium oxide, the second hardest substance known. Coloured crystals form the gem-stones, ruby, sapphire and topaz.

CRETACEOUS ... ... The third Period in the Mesozoic Era. The System of rocks formed in that Period.

CRUSTACEA ... ... A group of animals including the shrimps and crabs.

CULM ... ... Sandstones of Carboniferous in S.W. England.

CULTURE ... ... A comprehensive term covering the methods used by Early Man in making tools, weapons, ornaments, etc.

CURRENT BEDDING ... Type of bedding characteristically shown by sands deposited by moving water.

DACITE ... ... A fine grained extrusive igneous rock.

DENUDATION ... ... The gradual lowering and destruction of a landscape by weathering and erosion.

DERIVED FOSSILS AND ROCKS ... Derived from rocks of an earlier age, and usually water-worn.

DEVONIAN ... ... The fourth Period in the Palaeozoic. The System of rocks formed during that Period.

DIAMOND ...	... Crystalline carbon, the hardest known substance.
DIATOM ...	... Minute unicellular plants with siliceous valves.
DIOPSIDE ...	... A pyroxene.
DIORITE ...	... A coarse grained intrusive igneous rock.
DIP ...	... The tilt of a rock bed.
DIP ANGLE ...	... The angle of a dip to the horizontal.
DOGGERS ...	... Intensely hard, often rounded concretions of calcareous sandstone. The Dogger as a formation however, is a Jurassic sandstone in Yorkshire.
DOLERITE ...	... A fine grained intrusive igneous rock.
DOLOMITE ...	... A limestone, often pinkish, containing mineral dolomite, a double carbonate of calcium and magnesium.
DRIFT DEPOSITS	... Superficial, usually unconsolidated deposits on Earth's crust.
DRUMLIN ...	... Rounded mounds of rock debris deposited by moving glaciers.
DYKE ...	... Vertical sheets of an intrusive igneous rock.
DYKE SWARM	... Numerous dykes, radiating from a common source.
EOCENE ...	... The first of the sub-divisions of the Tertiary Period. System of rocks formed during this Period.
ERA ...	... The primary division of geological time.
EROSION ...	... The removal by wind and water of rock fragments, etc., following weathering.
EXTRUSIVE ROCKS	... Igneous rocks formed from magma, cooling on surface of the ground and not within rock cavities.
FAULT ...	... Vertical displacement of strata along a plane, the fault plane.
FAULT BRECCIA	... Breccia formed along plane of fault.
FELDSPARS ...	... The most important group of rock-forming silicates.
FELDSPATHOIDS	... Minerals related to feldspars but containing much less silica.
FLINT ...	... Amorphous siliceous rock occurring as nodules in chalk.
FOLDING ...	... Undulations in rock beds resulting from lateral pressure.
FORAMINIFERA	... Minute, unicellular marine animals with hard shells.

FORMATION ...	... A particular layer of rocks, such as a bed of coal or sandstone.
FOSSIL ...	... The remains (usually stony) of plants or animals that have resisted decay and have become buried in the ground.
FULL ...	... One of a series of parallel ridges forming certain types of shingle beach.
FULLERS EARTH	... Type of clay with affinity for water and grease.
GARNETS ...	... A group of complex silicates found especially in metamorphic rocks. They form very perfect red glassy crystals.
GASTROPOD ...	... Mollusc with shell in one piece.
GAULT CLAY ...	... A marine deposit of the Lower Cretaceous.
GEOLOGY ...	... Scientific study of structure and history of Earth's crust.
GEOMORPHOLOGY	... Study of landscape development.
GLACIER ...	... Mass of ice moving slowly down from ice-field.
GLACIAL ERRATICS	... Pieces of rock carried great distances by moving ice.
GLACIATION ...	... Time when a region is covered by a particular ice-sheet.
GLAUCONITE ...	... A green mineral formed on the floor of the ocean.
Globigerina ...	... A foraminifera with a minute chambered calcareous shell.
GNEISS ...	... A crystalline metamorphic rock, showing well developed banding of the constituent mineral crystals.
GONIATITES ...	... Cephalopods related to and preceding ammonites.
GRANITE ...	... The main type of intrusive igneous rock, containing quartz, feldspar and micas.
GRANODIORITE	... An intrusive igneous rock differing from granite in the proportion of its feldspars.
GRAPTOLITE ...	... Small floating colonial marine animals, confined to the Palaeozoic and now extinct.
GREENSAND ...	... Sand or sandstone containing glauconite.
GRITS ...	... Coarse grained sandstone.
GRYKES ...	... Vertical weathering cracks in limestone.
GYPSUM ...	... Hydrated calcium sulphate, when crystalline known as selenite and satin spar, and as alabaster when compact and fine grained.

HAEMATITE ...	...	Iron oxide with rounded lumpy surface.
HANGING VALLEY	...	High level tributary valley which drops steeply into main valley.
HERCYNIAN ...	...	See ARMORICAN.
HOLOCENE ...	...	See POST-GLACIAL.
HORNBLENDE ...	...	A rock-forming mineral of the amphibole group.
HORNFELS ...	...	A very tough metamorphic rock.
Homo sapiens	...	Generic and specific names for Man.
HUMUS ...	...	Blackish substance composed of decayed particles of plant material.
HYDRATION ...	...	A chemical change due to combination with water molecules.
HYRACOTHERIUM	...	Ancestor of the horse, living during the Eocene.
ICE AGE ...	...	Any geological period when ice sheets were particularly extensive, the most important being that during the Pleistocene.
Ichthyosaurus	...	Fish-like reptile living during Triassic to Cretacous Periods.
IGNEOUS ROCKS	...	Crystalline rocks formed from cooling of molten magma.
IMPRESSION ...	...	Cavity left in rock after fossil has been removed. Also known as IMPRINT and MOULD.
INDICATOR PLANTS	...	Plants that only grow in certain types of soil.
INTERGLACIAL	...	Relatively mild periods occurring between two glaciations.
INTRUSIVE ROCKS	...	Igneous rocks formed when magma cools, forced into cavities within pre-existing sedimentary rocks.
IRON AGE ...	...	A phase of the Post-glacial based on Human Cultures.
IRON PAN ...	...	Hard layer of re-deposited iron oxide in certain soils.
IRON STONE ...	...	Sedimentary rocks rich in iron ores, particularly oxides or carbonates.
JURASSIC ...	...	The second Period in the Mesozoic Era. The System of rocks formed during that Period.
KAOLIN ...	...	White clay resulting from chemical decomposition of feldspars in granite.
KEUPER ...	...	The upper part of the Triassic.
KNICK POINT ...	...	The point in a river profile where a rejuvenated river is cutting-back.

LACCOLITH	Very large masses of instrusive igneous rock.
LAMELLIBRANCHS ...	Bivalve molluscs.
LAVA	Extrusive fluid magma. Also the igneous rocks formed on cooling.
LEACHING	The washing out of soluble substances by rain.
LIAS	Marine deposit forming base of Jurassic.
LIGNITE	Soft, brown coaly substance, usually post-Carboniferous.
LIMESTONE	Sedimentary rock containing much calcium carbonate.
LIMONITE	A non-crystalline rusty brown iron oxide.
LITHIFICATION ...	The process of a soft sediment being turned into a hard rock.
LONG BARROW ...	Earthen burial mounds up to 300 feet long, built by Neolithic Man.
MAGMA	Molten rock issuing from below the Earth's crust.
MARBLE	Limestone metamorphosed by heating.
MARL	Strictly a calcareous clay, though often used as a Formation name even if non-calcareous.
MEANDER	Curves in course of river in lower part of its valley.
MEGALITH	Huge stone blocks used for burial chambers by Neolithic Man.
MESOLITHIC	The Middle Stone Age, a cultural phase of the Post-glacial.
METAMORPHISM ...	The transformation of rocks into new types by heat, pressure, etc.
MICAS	A group of rock-forming silicates, notable for their thin plate-like crystals.
MICA SCHIST	Schist containing numerous mica crystals.
MILLSTONE GRIT ...	Coarse Carboniferous sandstone.
MINERAL	A chemical substance, of definite composition and often crystalline, occurring naturally.
MIOCENE	The third of the sub-divisions of the Tertiary Period, and also the rocks formed at that time.
MORAINE	Rock material brought down by a glacier.
,, GROUND ...	Moraine developed beneath the ice.
,, LATERAL ...	Moraine developed at sides of the glacier.
,, TERMINAL ...	Moraine formed at foot of glacier.
MOULD	See IMPRESSION.
MUDSTONE	A moderately hard sedimentary clay.

Muscovite	A kind of mica with silvery white crystals.
Nappes	Recumbent folds that have become detached and moved horizontally far from points of origin, by lateral pressure.
Neolithic	New Stone Age, a cultural phase of the Post-glacial.
New Red Sandstone	General term for the Permian and Triassic sandstones.
Nodule	Rounded or flattened accumulations of a particular substance within a rock bed.
Old Red Sandstone...	Non-marine sediments of Devonian age.
Oligocene	The second of the sub-divisions of the Tertiary Period. Also rocks formed at that time.
Olivine	A dark green rock-forming silicate.
Onion Scale Weathering	The detaching of successive layers from a boulder following abrupt temperature changes at its surface.
Oolitic	The structure of certain limestones which are composed of small spherical grains of calcium carbonate.
Ordovician	The second Period of the Palaeozoic Era. The system of rocks formed during that Period.
Organic Deposits ...	Those formed mainly from plant and animal remains.
Orthoclase	A feldspar, containing potassium, characteristic of acid igneous rocks.
Ostracod	Minute freshwater crustacean with bivalved shell.
Ox-Bow Lake ...	The lake left behind when a meandering river takes a short cut during times of flood.
Palaeolithic ...	The Old Stone Age, a cultural phase of Man, corresponding approximately to the Pleistocene.
Palaeontology ...	The study of fossils.
Palaeozoic	The first Era whose rocks contain definite fossils.
Peat	The accumulation of partly decayed vegetable matter, usually black or brown.
Pegmatite	A granitic igneous rock with very large crystals.
Period	The secondary division of geological time, several Periods making up an Era.

Permian ... ... The sixth Period of the Palaeozoic Era. The System of rocks formed during that Period.

Petrology ... ... The study of chemical constituents of rocks.

Phyllite ... ... A greenish, shining, metamorphic rock with much mica and chlorite.

Piedmont Glacier ... Glacier with a greatly expanded foot.

Pillow Lava ... Submarine lava with characteristic lumpy form.

Plagioclase ... ... A mixture of feldspars containing sodium and calcium, found in both acid and basic igneous rocks.

Pleistocene ... ... The first of two sub-divisions of the Quaternary Period.

Pliocene ... ... The fourth of the sub-divisions of the Tertiary Period.

Podsol ... ... Soil profile particularly well developed on porous sands.

Post-Glacial ... The time interval between the end of the Pleistocene Ice Age and the present day. Also called Holocene and Recent.

Pot Hole ... ... Vertical hole of great depth in thick beds of limestone.

Pre-Boreal Phase ... A climatic stage in the Post-glacial.

Pre-Cambrian ... The vast length of geological time preceding the Cambrian. Almost entirely unfossiliferous.

Pterodactyl ... ... Reptiles of the Jurassic with bat-like wings.

Pyroclastic ... ... Composed of rock fragments thrown out by volcanoes.

Pyroxenes ... ... A group of rock-forming silicates.

Quaternary ... ... The second of the two Periods making up the Cainozoic Era.

Quartz ... ... Crystalline silica.

Quartzite ... ... Either a sandstone with siliceous cement, or a metamorphosed sandstone.

Recent ... ... A sub-division of the Quaternary Period, extending from the end of the Pleistocene to the Present Day. Also called Holocene and Post-Glacial.

Recumbent Fold ... A fold pushed back on itself so that it lies almost horizontally.

Red Clay ... ... Sediment accumulating in deepest parts of the ocean.

Red Crag ... ... Early Pleistocene deposits in East Anglia.

REJUVENATED	...	Term used for a river whose valley has been uplifted and its rate of erosion consequently increased.
RHAETIC ...	...	A period usually regarded as part of Triassic or Jurassic owing to scarcity of deposits of this age in Britain.
RHYOLITE ...	...	An acidic extrusive lava.
RIVER TERRACE	...	Flat marginal strip in valley, raised above present river level.
ROCHE MOUTONNÉE	...	Rock rounded and smoothed by passage of ice.
ROCK ...	...	A naturally occurring mass of one or more minerals. Thus used geologically, "rock" includes loose gravels and soft clays.
ROCK CRYSTAL	...	Large crystals of quartz.
ROCK FLOUR ...	...	Very fine particles of rock crushed by passage of ice.
SANDSTONE ...	...	Sedimentary rock composed in the main of quartz grains.
SAURIANS ...	...	An extinct group of reptiles flourishing in the Mesozoic.
SEAM ...	...	Rock bed containing particular substance, i.e. coal.
SCHIST ...	...	Shining metamorphic rocks, with a tendency to split into thin sheets.
SCREE ...	...	The steeply sloping mass of rock debris accumulating below steep crags.
SEDIMENTARY ROCK	...	Rocks formed by deposition of rock particles in more or less horizontal layers.
SEDIMENTATION	...	The deposition of the particles which make up a sedimentary rock.
SERIES ...	...	Sub-division of a rock System.
SERPENTINE ...	...	A mineral (often green) resulting from the metamorphism (by hydration) of magnesian rocks, especially those containing much olivine.
SHALE ...	...	Sedimentary rock splitting into very thin sheets.
Sigillaria ...	...	Giant horsetails which grew in the coal forests of the Carboniferous.
SILICA ...	...	Silicon dioxide.
SILICEOUS ...	...	Composed of silica.
SILL ...	...	More or less horizontal sheet of an intrusive igneous rock.
SILURIAN ...	...	The third Period of the Palaeozoic Era. The System of rocks formed during that Period.

SINK HOLES	Conical depressions caused by solution of limestone by rainwater.
SLATE	Hard rock splitting into sheets, usually metamorphosed volcanic ashes.
SOIL	Uppermost weathered layer of rocks, with addition of plant remains.
SOIL PROFILE	Sequence within soil shown in a vertical section.
STAGE	A sub-division of strata consisting of several Zones.
STALACTITE	Hanging masses of calcium carbonate deposited as lime saturated water evaporates in limestone caves.
STALAGMITE	Similar to stalactites in origin, but growing upwards from floors or caves.
Stigmaria	The roots of *Sigillaria*.
STRATA	The layers of a sedimentary rock.
SUB-ATLANTIC PHASE	A climatic stage in the Post-glacial.
SUB-BOREAL PHASE ...	A climatic stage in the Post-glacial.
SWALE	Depression in a shingle beach between two fulls.
SYENITE	A type of intrusive igneous rock.
SYNCLINE	Down folding of rock beds to form a trough.
SYSTEM	The rocks formed during the corresponding Period.
TALC	A soft silvery-green flaky material, resulting from the hydration of magnesium-rich rocks. It has great commercial value.
TERTIARY	The first of the two Periods making up the Cainozoic Era.
THRUST PLANE ...	The horizontal plane along which rocks may be pushed *en masse* during intensive folding. Virtually a horizontal fault.
TRACHYTE	A fine grained igneous lava.
TRIASSIC	The first Period of the Mesozoic Era. The System of rocks formed during that Period.
TRILOBITE	An extinct Palaeozoic animal related to the Crustacea.
TRUNCATED SPURS ...	Valley spurs flattened by passage of glacier.
TUFA	Irregular calcareous deposits formed round springs, etc.
TUFFS	Lithified beds of volcanic ashes.
TYPE LOCALITY ...	The place where the rocks of a certain formation were first described in detail.

UNCONFORMITY ... Junction between strata so disposed that upper beds rest at a different angle to the underlying older beds, following a period of erosion.

UNCONSOLIDATED ... The condition in a loose sediment in which the particles are not firmly cohesive.

VENT ... ... Vertical hole through which magma rises in centre of volcano.

VOLCANIC BRECCIA ... Breccia composed of fragments of lava.

WEATHERING ... ... The physical and chemical breakdown of rocks, in particular by oxidization and action of water.

ZONE ... ... A thickness of rock containing a particular fossil, the "Zone fossil."

ZONE FOSSIL ... ... A fossil with a characteristic form but relatively short time-range, selected to typify a Zone.

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